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Natural Resource Stewardship and Science

Stream Ecological Integrity at Little Bighorn Battlefield National Monument

Rocky Mountain Inventory & Monitoring Network 2007-2010 Stream Monitoring Report

Natural Resource Technical Report NPS/ROMN/NRTR—2014/882

ON THIS PAGE
The Little Bighorn River, LIBI in May 2009
Photograph by: B. Schweiger, ROMN

ON THE COVER
Melena Stichman (NPS, LIBI) and Rosie Fewings (NPS, ROMN) collect water samples while Alex Cahlander-Mooers (NPS, ROMN) measures stream flow in the Little Bighorn River, LIBI during a August 2009 sample event
Photograph by: B. Schweiger, ROMN

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from theRocky Mountain Network website (http://www.nature.nps.gov/im/units/romn), and the Natural Resource Publications Management Web site (http://www.nature.nps.gov/publications/nrpm/) on the Internet. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Contents

Contents (continued)

Contents (continued)

Figures

Figures (continued)

Tables

Tables (continued)

Appendices

Page

Executive Summary

The following report presents results from pilot monitoring of Stream Ecological Integrity (SEI) in the Little Bighorn River at Little Bighorn Battlefield National Monument (LIBI) from 2007-2010. Overall, the ecological integrity of the river during this time was mixed, with high quality water physiochemistry and physical habitat, but with some indication of non-reference biological conditions. A summary of key results is given in a Summary Condition Table that follows.

The general objectives of SEI monitoring are to document the status and long-term trends in ecological condition of streams and rivers in a park, and to use this information to help understand why stream conditions may have changed. Resource managers may, in turn, use information from SEI monitoring to make resource management decisions within their parks. The SEI protocol is an integrated and comprehensive approach to monitoring stream resources in parks within the Rocky Mountain Inventory and Monitoring Network (ROMN). The ROMN selected indicators of stream ecosystem condition as high priority Vital Signs in its planning process because streams are fundamental components of every ROMN park and their ecology is intimately linked and reflective of conditions in the watersheds they drain. Streams support a broad spectrum of ecological services including hydrologic cycling, nutrient processing, and wildlife habitat as well as socioeconomic functions including recreation, fisheries, and water sources. Finally, streams are sensitive to stresses such as excessive sediment and nutrient inputs, withdrawal for municipal and agricultural use, and changing climate making them ideal for long-term ecological health monitoring.

Our assessment has largely been conducted for informational purposes, outside of any regulatory context, to provide the park and its stakeholders with baseline information regarding the current condition of the Little Bighorn. The NPS does not have regulatory authority over the waters in LIBI or the authority to evaluate beneficial designated uses. For waters that are within Indian Country, tribes have jurisdiction once they develop a water quality standards program approved by the U.S. Environmental Protection Agency (EPA). The Crow Tribe has not yet done this for the Little Bighorn so this authority still resides with EPA. However, the EPA has also not yet done this for the Little Bighorn River so the NPS and ROMN have no accepted regulatory framework for understanding and managing LIBI water quality. Formal interpretation of any future Crow Tribe/EPA or current State of Montana water quality standards and impairment decisions are beyond the scope of these analyses and are not provided. Therefore, any comparisons we make using SEI or auxiliary data to water quality standards, criteria or assessment points do not officially include any statement as to whether a beneficial designated use was attained or not. However, NPS can participate with tribes or state in collecting and (informally) evaluating data used in the protection of water bodies in parks but that lie under state or tribal jurisdiction. Therefore, parks like LIBI can benefit from the nonbinding or informal data and interpretations in this report.

The ROMN defines the ecological integrity of a stream as the capacity to support and maintain a balanced, integrated and adaptive community of organisms, having a species composition, diversity, and functional organization comparable to minimally-disturbed natural streams in the ecoregion. The SEI protocol includes a broad spectrum of indicators to help evaluate the ecological integrity of the Little Bighorn River at LIBI. Core indicators include multiple measures of water and sediment physiochemistry (i.e., nutrients, metals, temperature); physical habitat (i.e., substrate composition, riparian cover, channel geomorphology); and community level assays of two important biological assemblages, macroinvertebrates, and algae. The latter provide an integrated aspect for assessing ecological integrity because these organisms respond to environmental conditions over time and space. We include measures of drivers (or stressors) and ecological responses, such that we may better understand the linkages between these and help parks apply these results to resource management. We are able to do this in large parks where we have a large sample size or, for single sites (LIBI), after we have a time series of data.

SEI methods are documented in a draft protocol and are largely derived from well-established and existing protocols developed by ROMN partners, including the EPA, the U.S. Geological Survey (USGS), and the Montana Department of Environmental Quality (MT DEQ). The application of standardized protocols across ROMN and partner stream monitoring sites facilitates comparison of streams and rivers within an ecoregion.

SEI data were analyzed following well-established methods. Biological response was emphasized because the presence and health of populations of key taxa are indicative of overall stream health. Bioassessment tools include Multimetric Indices, which combine multiple elements of an assemblage into a synthetic assay of community structure; a River Invertebrate Prediction and Classification model, which compares an expected species list at each site with what is actually collected, and models that describe the prevalence of algae taxa that increase when specific stressors occur in a stream. Water quality monitoring data were interpreted using existing or proposed standards (also called criteria). For biology and habitat response, criteria from state and federal agencies were used as relevant to the Little Bighorn in LIBI. Finally, for select responses, additional or alternate assessment points were derived from reference sites in partner monitoring stream networks within the Northern Great Plains ecoregion to facilitate comparison to a broader scale reference state.

Throughout this document, we use the terms “reference” and “non-reference” to describe how an indicator relates to criteria or other assessment points. An indicator can be in a **reference** state if it lies within a range of values that represent an *intact state* (i.e., “good condition”) from an ecological or other perspective (e.g., human health). In contrast, the indicator may also be in a **non-reference** or degraded state (“poor condition”). Or, in many cases, an indicator may be intermediate, somewhere between a reference and non-reference state.

This effort has been, and will continue to be, a cooperative undertaking between ROMN staff, aquatic scientists, especially from USGS, EPA, and MT DEQ, and most importantly LIBI management and staff. Our results represent the efforts of many dedicated scientists and resource managers over several years and are valid, representative, and address our objectives. They should be useful for understanding and, within the constraints of the protocol, managing the Little Bighorn. However, our data are incomplete—we are at the beginning of an effort that will take many years before there is sufficient data to understand long-term trends. As we accrue data we will also continue to improve our understanding of the mechanisms and drivers behind aquatic system health and specifically, SEI responses. Future SEI monitoring will permit continued analysis of data relative to the criteria and thresholds for the state and Northwestern Great Plains ecoregion. These analyses will help scientists continue to monitor the most cost-effective and management-relevant suite of indicators of ecological integrity of the Little Bighorn in LIBI.

LIBI SEI Summary Condition Table

SEI results for LIBI are summarized in the following *draft* resource condition summary table. We include example vital sign and indicators, a brief description of results and patterns and symbolize the status, trend, and our confidence in those summaries. This table is a considerable simplification of the detail in the full report and should be used with caution. For example, some indicators within a category have divergent patterns (i.e., one may be in a reference state and another is not). We qualitatively weigh this variance using our best professional judgment to derive an overall assessment for each category.

The following provides a key for the symbols used in the Summary Condition Table.

Status		Trend		Confidence	
	Significant Concern/ Non-reference		Condition is Improving/ Improving trend		High
	Caution/ Intermediate		Condition is Unchanging/ Stable trend		Medium
	Good Condition/ Reference		Condition is Deteriorating/ Decreasing trend		Low
		No symbol	Unknown trend		

NOTES:

The status of a vital sign or indicator can be in a "reference state," that is, based on our knowledge of the vital sign within a range of values considered "healthy" from an ecological or other perspective (e.g., human health). The status may also be "non- reference" or unhealthy; or it may be in a state that is "intermediate" between reference and non-reference.

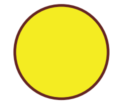
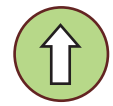
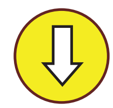
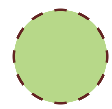
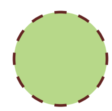
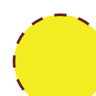
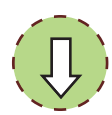
These designations are be simplified into green circles for "good condition," yellow circles for "intermediate" or "caution," or red circles for "significant concern."

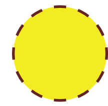
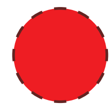
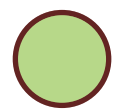
The trend in condition over time is also symbolized; improving conditions are represented by up-arrows, deteriorating conditions are represented by down-arrows, and stable conditions are represented by horizontal or flat arrows. In some cases, we do not have sufficient data over time to evaluate trends, for those vital signs or indicators there is no arrow symbol within the circle.

Confidence in our evaluation of status and trend is symbolized by the thickness or character of the outside line of the symbol. "High" confidence in the data and our interpretation is represented by a thick line, "medium" confidence is represented by a thin line, and "low" confidence is symbolized by a dashed line.

Summary Condition Table

Little Bighorn River at LIBI, 2007 to 2010

Vital Sign (Example Indicators)	Summary	Symbol
Overall ecological integrity	The ecological integrity of the Little Bighorn from 2007 to 2010 was largely intact and of medium to higher quality. Results were somewhat mixed, with high quality water physiochemistry and physical habitat, but the weight of biological evidence suggests a non-reference biological condition. However, the available biological metrics may not be well suited to the Little Bighorn and in general we have low to medium confidence in this interpretation (in other areas we have greater confidence in our assessment). We lack data to assess the overall trend in condition.	
Water physiochemistry (major ions, nutrients, metals)	Nutrients, major ions, and metals concentrations were all acceptable with few exceedances of State of Montana water quality criteria for aquatic life (or human health). Maximum (but not median) sulfate concentrations were higher than at ecoregion reference sites. While patterns are mixed, the long-term trend in several water physiochemistry parameters may be improving. We have medium confidence in our assessment of major ions, nutrients, metals at LIBI.	
Water in-situ chemistry (pH, conductivity, DO, temperature)	All of the core NPS parameters were in an acceptable reference range. Dissolved oxygen needs more careful monitoring. The long-term trend in stream temperature suggests rising water temperature —or a deteriorating condition (but the period of record is short). We have medium confidence in our assessment of *in situ* parameters at LIBI.	
Sediment chemistry (metals)	Most metals were present in low concentrations and did not exceed informal consensus-based sediment criteria. We suspect the source of most metals is natural. We lack data to assess trends in metal concentrations. We have lower confidence in our assessment of sediment chemistry at LIBI given the lack of clearly relevant criteria.	
Habitat, sediment (size, stability)	Fine substrates in the Little Bighorn channel were less prevalent than in ecoregion reference sites. Bed sediments were also slightly less mobile than expected. If we restrict data to just littoral areas, however, the cover of fines is high and may explain reduced biological condition. However, the channel bedform and these sediment dynamics are probably not relevant in ongoing natural processes like bank sloughing of concern to the park. We need more data to confirm these patterns and to assess trend.	
In stream and riparian habitat (complexity, cover, disturbance)	In-stream habitat was generally in a reference state with a fairly complex bottom profile and sufficient woody debris. However, there was more filamentous algae cover than ideal, riparian vegetation cover was patchy, especially on the west or non-park bank, and some adjacent potential stressors in the floodplain were more common than in ecoregion reference sites (even with the fairly intact riparian corridor on the park side). Invasive plants were fairly common, and some occurred with higher frequency than in ecoregion reference sites. We need more data to confirm these conclusions and assess trend.	
Habitat, stream flow (amount and timing)	Stream flow during 2007 to 2010 relative to the period of record suggest SEI monitoring occurred in variable but largely average water years. Long-term USGS gauge data suggests a shift in timing of peak flows to later in the summer, and a small but marginally significant decrease in total annual flow We have lower confidence in our assessment of stream flow at LIBI given the distance to the gauge near Hardin.	

Vital Sign (Example Indicators)	Summary	Symbol
Biological communities, macroinvertebrates (MMI and RIVPACS metrics)	Patterns across macroinvertebrate metrics were complex. The weight of evidence suggests that there was a non-reference community present. Littoral fine sediment may be the primary cause behind a degraded condition but it is not clear if the level of fine sediments at LIBI are natural or are caused by anthropogenic activities in the watershed. We lack data to assess trends. We have lower confidence in our assessment of benthos communities at LIBI due to possible imprecision in some macroinvertebrate models developed for warm water or plains rivers like the Little Bighorn.	
Biological communities, diatoms (increaser metrics, MMI)	Like macroinvertebrates, most diatom metrics suggested a degraded conditions in the river, especially in response to sediment and nutrients. Diatoms are the base of the food chain and the lack of an intact diatom community may be one of the reasons why we also see lower quality macroinvertebrate assemblages. We lack data to assess trends. We have lower confidence in our assessment of benthos communities at LIBI due to possible imprecision in some diatom models developed for warm water or plains rivers like the Little Bighorn.	
Aquatic invasives (presence)	No aquatic invasive species were found, although the New Zealand mudsnail is in the Bighorn River watershed and likely on the move. SEI monitoring will watch closely for these and other invasive species over the coming years. We have medium confidence in our assessment of aquatic invasives at LIBI.	

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Thanks are due to park staff members who shared their field labor, experience and knowledge of streams and other park resources. Special thanks to Melana Stichman, Michael Stops, and Katie Hester.

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Introduction

The National Park Service Inventory and Monitoring Program

The purpose of the National Park Service (NPS) Inventory & Monitoring (I&M) Program is to develop and provide scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems. As part of the NPS's effort to improve park management through greater reliance on scientific knowledge, a primary role of the I&M Program is to collect, organize, and make available natural resource data and to contribute to the Service's institutional knowledge by facilitating the transformation of data into information through analysis, synthesis, and modeling of specific key "vital signs." The I&M Program defines the term vital sign as a subset of physical, chemical, and biological elements and processes of park ecosystems that is selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Fancy et al. 2009).

The Rocky Mountain Inventory and Monitoring Network (ROMN) is comprised of six NPS units: Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), and Little Bighorn Battlefield National Monument (LIBI), Montana; and Florissant Fossil Beds National Monument (FLFO), Great Sand Dunes National Park and Preserve (GRSA), and Rocky Mountain National Park (ROMO), Colorado (Figure 1). Through a comprehensive three-year scoping process, the ROMN and its partner parks and scientific collaborators, identified 12 high-priority vital signs for focused long-term monitoring. The vital signs include: Wet and Dry Deposition; Weather and Climate; Water Chemistry; Surface Water Dynamics; Freshwater Communities; Invasive/Exotic Aquatic Biota; Groundwater Dynamics; Wetland Communities; Invasive/Exotic Plants; Vegetation Composition, Structure, and Soils; Focal Species (Beaver, Elk, Grizzly Bear, and GRSA Endemic Insects); and Landscape Dynamics (Britten et al. 2007). By monitoring these vital signs in national parks across the network, the ROMN aims to efficiently provide comparable long-term ecological health information in national parks across broad latitudinal and elevation gradients from the southern to the northern Rocky Mountains.

Stream Ecological Integrity (SEI) monitoring in LIBI addresses five of ROMN's 12 high-priority vital signs: water chemistry, surface water dynamics, freshwater communities, invasive/exotic aquatic biota, and invasive/exotic plants. Three other high priority vital signs are indirectly linked with the SEI protocol including: landscape dynamics, wet and dry deposition, and weather and climate. The SEI protocol in LIBI is a multi-faceted ecological health approach to monitoring streams as guided by a detailed Stream Ecological Integrity (SEI) protocol (Schweiger et al. In Review). The SEI protocol describes an integrated approach to understanding status and trend in stream ecological condition, capturing the strengths of both fixed-site water quality-based approaches and probability surveys.

Purpose of Report

This report, *Stream Ecological Integrity at Little Bighorn Battlefield National Monument*, presents summaries and general interpretation of SEI work conducted during 2007-2010 at LIBI. We provide key data and results in the main body of the report. Other data or results are in the appendices or are available upon request from the ROMN.

Because this is the first report on SEI monitoring at LIBI, we include justification and some detail for key elements of the protocol; readers experienced in stream monitoring and assessment may only need to skim the Introduction and Methods sections. The SEI protocol (Schweiger et al. In Review) provides additional rationale for the design and field elements, summaries of analytical methods, overviews of data management and an administrative plan for long term implementation. The SEI protocol

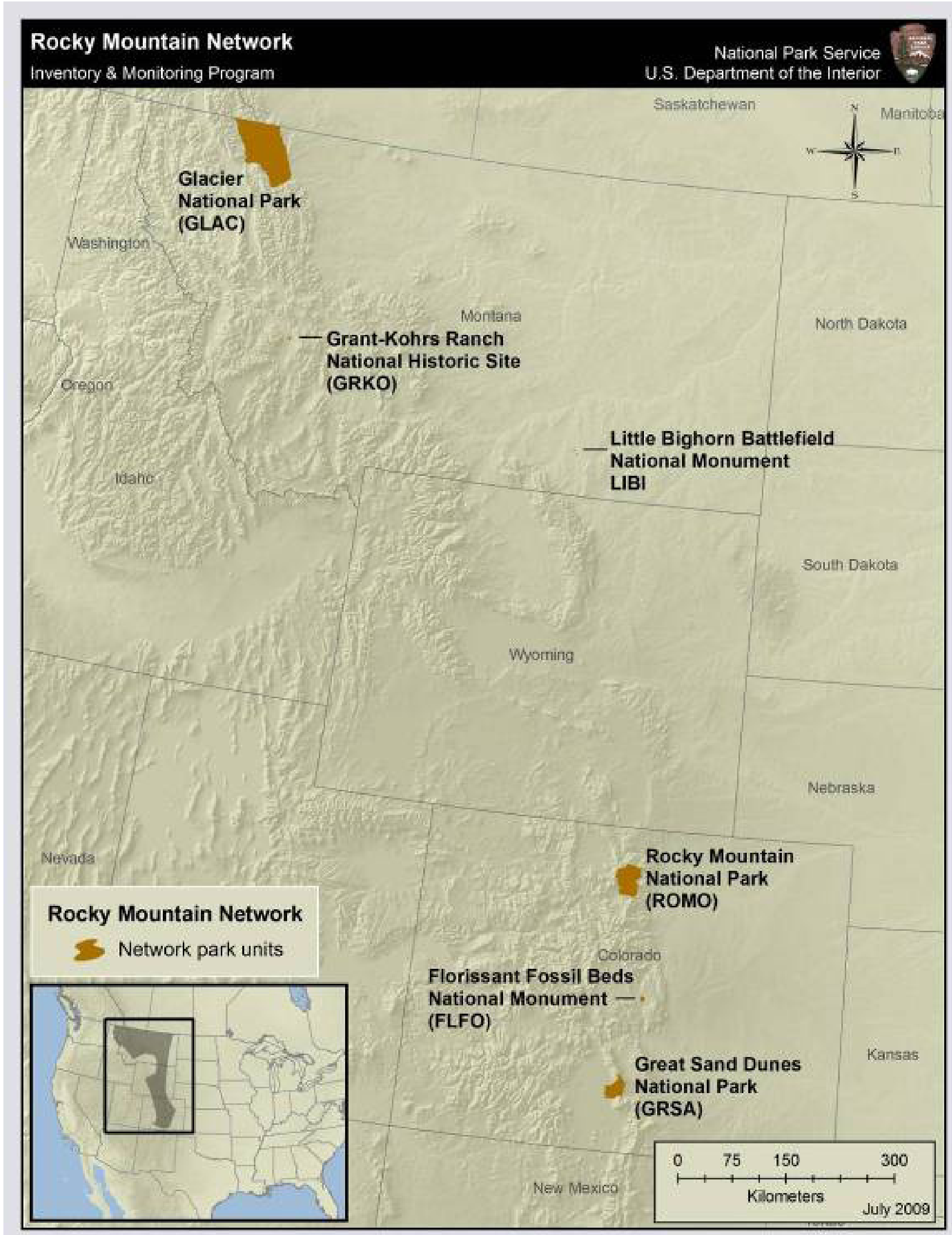


Figure 1. Little Bighorn Battlefield National Monument in relation to other parks in the ROMN.

also includes a series of standard operating procedures (SOPs) that provide detailed instructions for executing field, analytical, and select administrative components of the protocol.

Stream Ecological Integrity: Synthetic Index to General Condition

The SEI protocol focuses on the "ecological integrity" of streams. Ecological integrity is the capacity to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region (Karr 1991). Ecological integrity is a complex, multidimensional concept and usually a single indicator or vital sign is insufficient to characterize it. Therefore, we monitor an integrated set of response measures such as community-level composition, stream habitat (including hydrology), and water chemistry. The ROMN recognizes that ecological integrity may not be the primary goal of park resource management, particularly at historical parks like LIBI where cultural resource management may take precedence. Moreover, monitoring ecological integrity may not provide project-specific results for a single, focused issue in a park like "effectiveness monitoring" would. The ROMN works with network parks to develop monitoring approaches that are specific to each park and the key issues impacting stream condition in a given system, integrating the broader, longer-term concepts within ecological integrity with more case specific needs.

The ecology of streams and rivers is both intimately linked with and reflective of the watersheds they drain (Hynes 1972). A defining feature of streams and rivers is their dependence on the landscape in which they reside for inputs of energy and nutrients (Naiman 1992, Hunsaker and Levine 1995). Streams support a broad spectrum of ecological services including nutrient processing, hydrologic cycling, critical habitat for facultative (e.g., beavers) and obligate (e.g., stoneflies) species, and multiple socioeconomic functions for humans (e.g., water sources, fisheries). Moreover, because streams are typically highly sensitive to stressors at both local and landscape scales, they are one of the most useful types of ecosystems for long-term ecological monitoring.

Despite the many services they provide, streams are among the most significantly altered ecosystems in North America. Streams face numerous and varied threats, including impacts from climate change, atmospheric deposition, altered hydrology, acid mine drainage, agriculture, pollution from boats, invasive species, erosion, improper sewage plant or drain field operations, and storm water runoff. Some of the day-to-day and long-term management decisions at LIBI are at least partially connected to the Little Bighorn. Fisheries, water chemistry, surface water quantity, riparian composition and function can be pressing matters for park resource managers. Proper functioning of the Little Bighorn River and associated riparian habitat is of great importance to NPS management since cultural resources associated with battle can be threatened by floods and erosion and the River and riparian community are important components of the cultural landscape.

The Stream Resource at Little Bighorn Battlefield National Monument

The Little Bighorn Battlefield National Monument (LIBI) is located within the Little Bighorn River Valley in south-central Montana near the town of Crow Agency (Figure 2 and Figure 3). The 3.08 km^2 monument sits on terraces above the floodplain of the Little Bighorn River (Figure 4). A small area (approximately 0.20 km^2) along the western boundary of the monument extends onto the floodplain of the river, with the legal park boundary designated by the high water mark on the right (or east) bank of the river. LIBI is situated along the lower reaches of the Little Bighorn River, which drains an area of about 3,370 km^2. The river originates in both the Wolf (or Rosebud) Mountains and Big Horn Mountains in Wyoming and drains north for a distance of about 130 km through foothills and a broad alluvial valley. The confluence of the northward-flowing river with the Bighorn River is near Hardin, Montana, to the northeast of LIBI. Lodge Grass and Pass Creeks are the main perennial tributaries, and Owl and Reno Creeks are the largest ephemeral tributaries. There are no perennial or ephemeral streams flowing through the monument. There are several ephemeral springs and at least one alkaline seep in the Custer unit.

The Little Bighorn area of southeastern Montana has been home to various Native American tribes since prehistoric times. Archaeological evidence suggests that human activities have taken place in the region for the last 10,000 years. Throughout most of that time, people using the area practiced a highly mobile hunting and gathering subsistence. Nomadic tribes demonstrating a bison-centered lifestyle characterize the historic period beginning around 200 years ago. The Apsáalooke people entered the area by the early 1800s, seeking access to rich bison hunting grounds of the Little Bighorn Valley. Although the Little Bighorn was acquired by the United States as part of the Louisiana Purchase in 1803, few whites, aside from sporadic traders and explorers, ventured into the area before the late 1800s (Greene 2008).

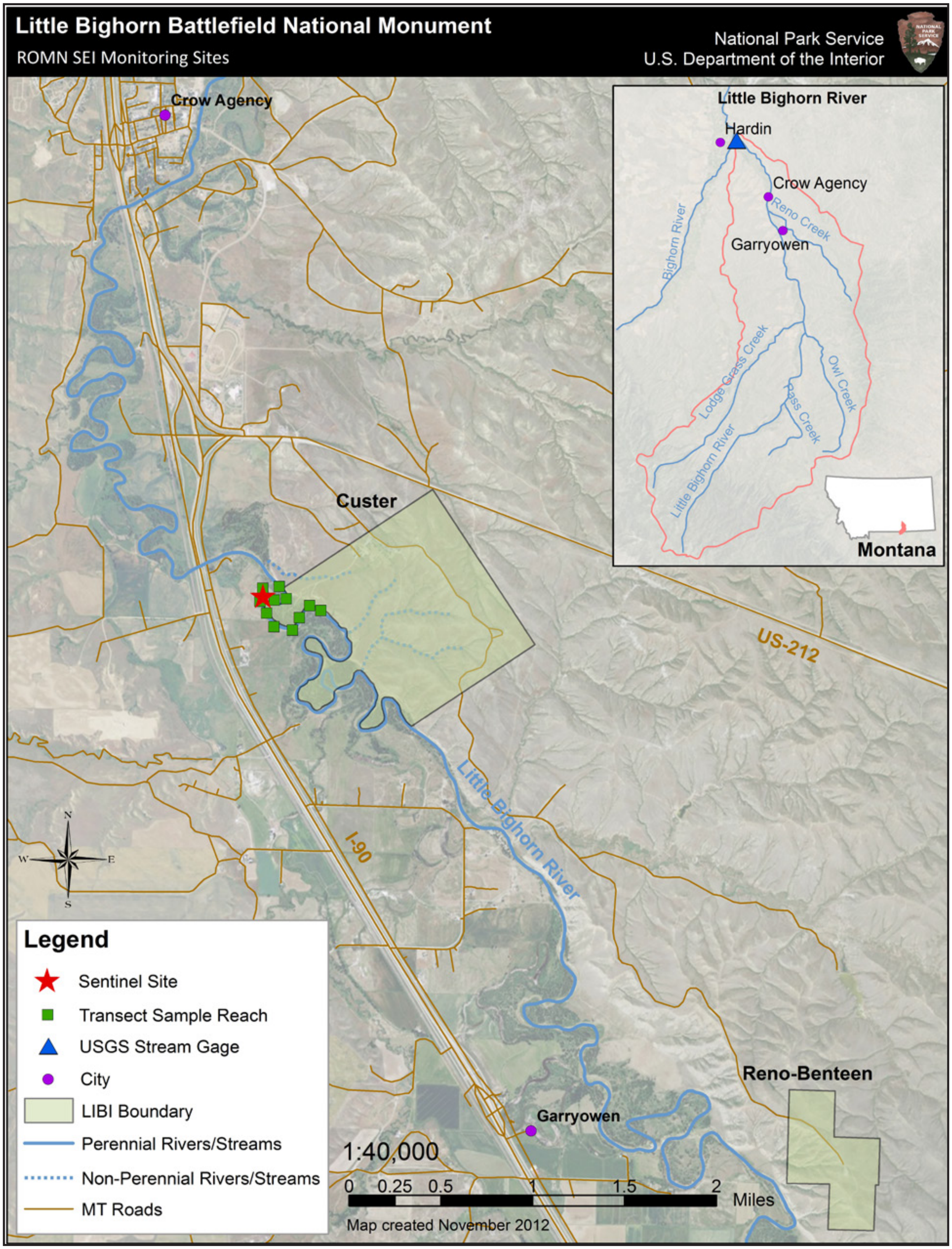


Figure 2. Little Bighorn Battlefield National Monument showing the SEI sample site locations. The green squares show each transect location sampled during a full sample event and the red star gives the location of sentinel sample events. Inset shows the Little Bighorn River watershed including the USGS stream gauge (blue triangle) about 22 km river miles north of the Monument.

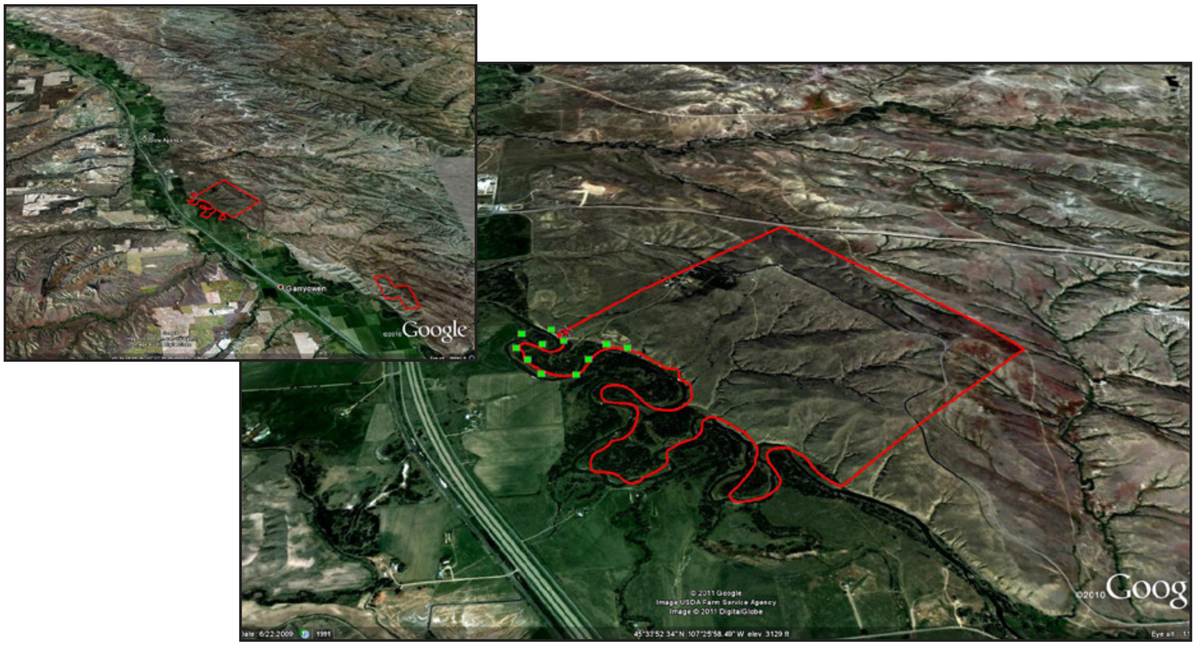


Figure 3. Oblique view (looking North) of the Little Bighorn River at Little Bighorn Battlefield National Monument (only the Custer Battlefield unit is shown in in the larger image). Background imagery is early fall 2010 (courtesy Google Earth). The small town of Crow Agency, MT is shown in the background of the larger image. The green squares show each transect location sampled during a full sample event and the red star gives the location of where sentinel sample events occur. The inset map shows the USGS gauge near Hardin and both units of the Monument. Stream flow is from the foreground of the image.

The Crow Indian Reservation was established by the Treaty of 1851. Custer Battlefield National Cemetery was established in 1879 by General Orders Number 79 to protect the graves of Seventh Cavalrymen who fell in the Battle of the Little Bighorn. Later, as the frontier era came to a close, the role of the cemetery expanded. In 1886 the boundary was established, setting aside one square mile within the Crow Reservation for military purposes. In 1926 an Act was passed authorizing the acquisition of the Reno-Benteen site. The War Department managed the two sites until 1940 when they became part of the National Park system.

Land use activities in LIBI are related to visitation (averaging 320,000 visitors annually), which peaks in July and August. Grazing has been excluded from the Custer Battlefield since 1891, and the Reno-Benteen Battlefield since 1954 although occasional trespass grazing occurs when fences are compromised. Since the Custer Battlefield boundary fence is on the bluffs, grazing occurs occasionally between the Little Bighorn River and the fence. The monument has a visitor center, several administrative buildings and residences, numerous cultural features, three improved trails and two unimproved trails, and several kilometers of roads. The main land use in the reservation surrounding LIBI is irrigated agriculture along the valley floor for cultivation of alfalfa, pasture grass, corn, and sugar beets (Tuck 2003). The higher terraces and foothill areas are primarily used as rangeland for cattle.

NPS/BILLY SCHWEIGER

Figure 4. The Little Bighorn River in the Little Bighorn Battlefield National Monument during the fall of 2007. The top of the SEI sample reach begins on the left side of this image and extends around the large bend for 1.2 kilometers. Stream flow is from the left side of the image.

Why Monitor the Little Bighorn River?

There are several reasons behind the choice to conduct long-term stream monitoring in LIBI. In general, streams and rivers are fundamental components of the ecological and cultural context of ROMN parks like LIBI (Seastedt et al. 2004, Hauer et al. 2000, Hauer et al. 2007, Mast et al. 2005, Stottlemyer et al. 1997). They are often what visitors come to see, what they remember when they leave, or especially in the case of LIBI, form an important backdrop to the historical events preserved by the park. The NPS recognizes that aquatic resources are some of the most critical and biologically important resources in the national park system and that they are vulnerable to degradation from activities both within and external to parks.

Current Importance of the Little Bighorn to LIBI and the Hardin Area

The Little Bighorn River and its associated hydrogeologic system is a primary resource at LIBI and the park protects a small portion of the Little Bighorn drainage. The river is integral to many of the ecological processes occurring within the park, and can play an important role in park operations. For example, LIBI water rights allow the park to divert water from the river for fire suppression. LIBI obtains drinking water from an in-park, potable (chlorinated and filtered) water system (supplied from the Little Bighorn) and wastewater is handled by the septic and leach system which is located southwest of the maintenance shop on the uplands above the river bottom.

The Little Bighorn River is also a key lifeline of the Little Bighorn Valley and the Crow Reservation. It is an important source of water for irrigation in the valley and as a water supply for many towns including Lodge Grass and Crow Agency. It is also a key source of recreation, including fishing and rafting.

Flooding

Overbank flows (flooding) represent an important floodplain function for low-gradient rivers such as the Little Bighorn. This was dramatically illustrated in the spring of 2011 (outside of the period of record of this report) when discharge on the river was near its historic peak (396 m^3/s, or about 14,000 ft^3/s; USGS 2011). During periods of overbank flow, significant detention storage of floodwaters can occur, moisture levels of floodplain soils and underlying aquifers are recharged, and fine sediments are deposited on floodplain surfaces. These, and several other processes, are critical to the maintenance of a healthy river ecosystem. However, a primary concern regarding flooding at the national monument is the potential loss of artifacts on the floodplain and riverbanks; this may require some type of stabilization to preserve potential collection sites (NPS 2007).

While the ROMN SEI protocol does not replace the ongoing, continuous, and real-time monitoring of stream flows by the USGS at the nearby Hardin gauge, or the episodic work by the NPS Water Resource Division (see below), many of the physical and biological components of the protocol directly or indirectly measure the impacts of floods on the river ecosystem at LIBI.

Historical Role of the Little Bighorn River

The Little Bighorn River played a central role in the historical events that LIBI commemorates (Rickey 2005; Figure 5). Rivers like the Little Bighorn became popular summer religious rendezvous sites for the various bands of the Lakota tribe During the Battle of Little Bighorn in 1876, the multi-tribe encampment was in the valley. River fords were significant in battle movement within the mostly un-wadeable channel. During the Reno valley fight, Indians burned timber to hide the encampment withdrawal downstream. Water supply for Reno and Benteen's troops came from the river through what is now known as water carrier's ravine.

Ecological Monitoring Considerations

The mission of the NPS I&M program and the ROMN is to provide long-term ecological monitoring data and information for a suite of "Vital Signs" to park managers to assist them in preserving park resources unimpaired for the enjoyment of current and future generations. The ROMN has implemented Stream Ecological Integrity monitoring at LIBI to monitor several important Vital Signs including water quality and chemistry, surface water dynamics, invasive/exotic aquatic biota and freshwater communities (Britten et al. 2007).

Understanding and managing streams and rivers is best accomplished by treating them as complete hydrologic systems within a watershed where the natural processes that deliver water, sediment and woody debris are maintained and human disturbances are minimized. Important natural processes for healthy stream system functioning include natural processes of flooding, stream migration and associated erosion and deposition that results in natural habitat features such as floodplains, cutbanks and river bluffs, riparian habitats, accumulations of woody debris, terraces, gravel bars, riffles, pools, etc. ROMN monitoring aims to provide data and understanding of the Little Bighorn River hydrologic system and these natural processes (Schweiger et al. In Review). *While the regulatory considerations summarized below also provide an important context for SEI monitoring, the emphasis of long-term ecological monitoring within the protocol is a key distinction from other monitoring conducted by the State of Montana or other federal agencies like the EPA.*

Regulatory Considerations

Streams and rivers are one of the more regulated natural resources and multiple federal and state programs must be implemented by NPS and its partners to protect aquatic habitat and its many functions. The National Park Service is required to manage all park units in accordance with the Organic Act and other laws so as not to be "in derogation of the values and purposes for which these various areas have been established..." (General Authorities Act, NPS 1970). Under the General Authorities Act, all resources, including water resources of a park, are protected by the Department of the Interior/National Park Service. Only an act of Congress can change this fundamental responsibility of the NPS.

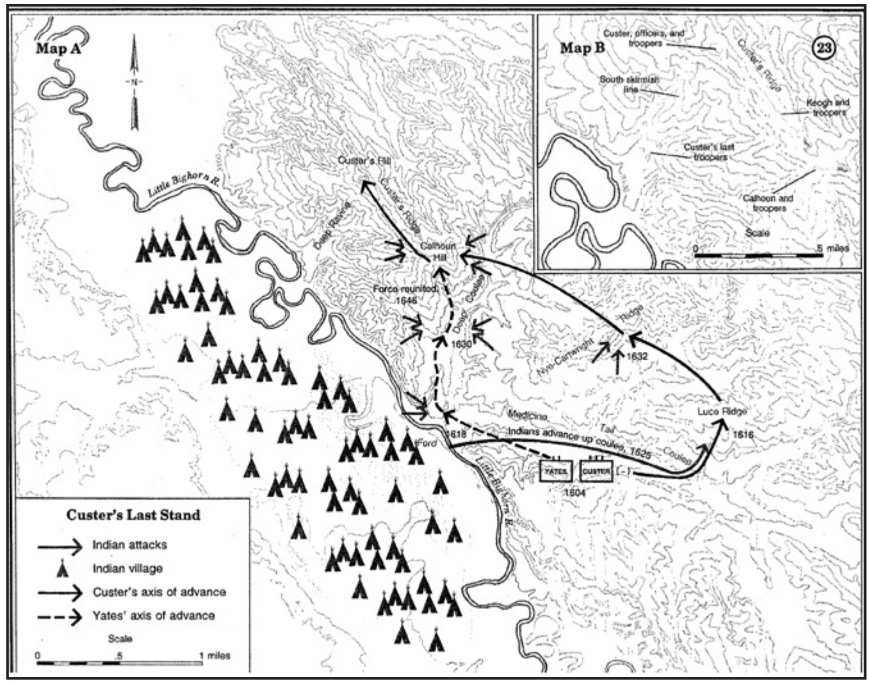


Figure 5. Map of the battle of the Little Bighorn in the Little Bighorn Battlefield National Monument showing the importance of the river in the battle dynamics. Map courtesy of Roberston (2011).

<u>NPS Policies</u>

The NPS Organic Act, the Code of Federal Regulations, and NPS Management Policies (2006) broadly require park management to maintain, rehabilitate, and perpetuate the inherent integrity of aquatic resources and processes. NPS policies direct park managers to work with the appropriate partners (e.g., the Crow Tribe, MT DEQ, and the EPA) to obtain the highest possible standards for park waters within the framework of the Clean Water Act (CWA) and to maintain or restore water quality. For smaller "flow through" parks like LIBI, this is complex given the small part of the river's watershed within LIBI. Moreover, the nested location of LIBI in the Crow Reservation (see below) creates a unique context for monitoring, managing and protecting the Little Bighorn River in LIBI.

<u>Clean Water Act</u>

The CWA, first promulgated in 1972, is designed to maintain and restore the chemical, physical, and biological integrity of the nation's waters including waters in national parks. As part of the act, Congress recognized the primary role of the states and tribal nations (see below) in managing and regulating water quality. Section 313 of the CWA requires that all federal agencies comply with the requirements of state law for water quality management, regardless of other jurisdictional status or landownership. The MT DEQ implements the protection of water quality for the waters of the state (but see below) under the authority granted by the CWA through best management practices and through water quality standards. Standards are based on the designated uses of a water body or segment of water, the water quality criteria necessary to protect that use or uses, and an anti-degradation provision to protect the existing water quality. Water Quality standards are the foundation of a water quality-based pollution control program as mandated by the CWA. Water quality standards define the goals for a waterbody by designating its uses, setting criteria to protect those specific uses, and establishing provisions such as anti-degradation policies to protect waterbodies from pollutants. The state's anti-degradation policy is a tiered approach to maintaining and protecting various levels of water quality. Minimally, the existing uses of a water segment and the quality level necessary to protect the uses must be maintained. The second tier provides protection of existing water quality in segments where quality exceeds the fishable/swimmable goals of the Clean Water Act. The third tier provides protection of the state's highest quality waters where ordinary use classifications may not suffice; these are classified as Outstanding Resources Waters (ORW).

<u>Water Quality in Indian Country</u>

Montana water quality standards apply to all waters within the State of Montana, with the exception of those waters that are within Indian Country (as defined in 18 U.S.C. Section 1151). In these cases, the tribes have jurisdiction once they develop a water quality standards program that includes designated appropriate uses, criteria and anti-degradation policies that are approved by EPA. The Crow Tribe has not yet done this for the Little Bighorn so this authority still resides with EPA. However, the EPA has also not yet done this for the Little Bighorn River so the NPS and ROMN have no accepted regulatory framework for understanding and managing LIBI water quality.

Interpreting ROMN Stream Ecological Integrity Monitoring Data

As emphasized in several places in this report, the primary motivation for SEI monitoring is to understand and document the long-term ecological condition of LIBI's aquatic resources in order to better protect and manage them. However, the NPS does not have regulatory authority over waters in LIBI—any regulatory action would be the responsibility of the Crow Tribe and/or the EPA.

For our purposes, we use criteria/assessment points that we feel are most useful in the ecological interpretation of SEI and associated auxiliary data (see below and Appendix C). We use current State of Montana criteria, older criteria/assessment points no longer in use by the State, criteria/assessment points still in development by the state, federal water quality standards, and novel reference assessment points we develop from ecoregional reference sites. In most cases, we emphasize current standards from the State of Montana as these are often conservative and rigorous and have local applicability. *In the future, if the Crow Tribe or EPA develop a water quality standards program for the Little Bighorn River in the Crow Reservation, we will emphasize this framework in our interpretation of ROMN SEI data.*

Legal/Regulatory Status of the Little Bighorn River at LIBI

Water use classifications for all stream segments in Montana were established by the State of Montana (Administrative Rules of MT 17.30.611 as in MT DEQ 2002). The Water Resource Division of the NPS compiles data on protected uses and any impairment status of waters in all NPS units. Table 1 presents this summary data for LIBI as of 2009 (NPS 2012).

The mainstem of the Little Bighorn River in the vicinity of LIBI (Little Bighorn River from Cottonwood Creek to the Little Blackfoot River) has a use classification of B-2, which is suitable for drinking, culinary, and food processing purposes after conventional treatment; bathing,

Table 1. Summary of designated waters in the Little Bighorn Battlefield National Monument as of 2009 (NPS 2012). Note that the extent numbers are restricted to the park's boundaries or to adjacent* waterbodies. ORW and 303(d) designation applies to all flowing water types.

Waterbody Type	Stream Miles	303(d) Impaired Stream Miles	Beneficial Use Class.	Outstanding Natural Resource Waters?	303(d) in Watershed?
Perennial Stream/River	0	0	B2	NO	NO
Intermittent Stream/River	1.97	0			

Waterbody Type	Stream Miles Adjacent*	303(d) Impaired Miles Adjacent*
Perennial Stream/River	3.2	0
Intermittent Stream/River	0	0

*Adjacencies were defined as any water feature that shares a boundary with a park. It is important to note that identifying adjacent hydrographic features may include some level of subjectivity and require a certain degree of judgment by the processor. Other sources of information, such as reviewing land segment maps and contacting park staff, were utilized whenever possible to verify adjacent features. Below are some examples of adjacency and how they were dealt with. See NPS (2012) for details.

swimming, and recreation; growth and marginal propagation of salmonid fishes and associated aquatic life; waterfowl and furbearers; and agricultural and industrial water supply. There are no current impairments at LIBI or on the Little Bighorn River above the battlefield

Climate Change

NPS Vital Signs monitoring is a long-term effort. Therefore, it should effectively respond to long-term changes in stream condition given shifting climate regimes. Changes in stream hydrology in the West over the past fifty years due to climate changes are well documented (Barnett et al. 2008) and these changes are expected to continue. Physical, chemical, and biological characteristics of aquatic ecosystems are well documented to act as indicators of impacts due to climate change (McKnight et al. 1997). Even modest temperature increases in the western United States may cause significant changes to the hydrologic cycle, as manifested in earlier snowmelt, earlier ice-out on lakes, reduced summer base flows (Dettinger et al. 2004), a lower snowpack volume at lower to mid elevations (Knowles et al. 2006), and increased flooding due to rain-on-snow events in winter (Heard 2005), especially when coupled with dramatic precipitation events such as in the spring of 2011. Hydrographs (i.e., the magnitude and timing of spring run-off) will likely shift to earlier floods. These changes will, in turn, likely affect the seasonal dynamics of stream and riparian biota (Palmer and Bernhardt 2006).

While more proximate, classic stressors impact many ROMN streams (especially at LIBI), climate change may be the most important direct and indirect stressor over the long term. However, many of the effects of climate change may take some time to appear and most will be confounded with other sources of stress. Therefore, the SEI protocol is designed to allow measure of the broad spectrum of stressors that might impact stream condition across multiple time scales in a system like LIBI such that we can attempt to tease apart these patterns.

Aquatic and Riparian Invasive Species

Climate induced changes in the hydrological cycle and multiple proximate direct disturbances often lead to changes in species distribution including invasion by taxa that can threaten native or endemic species and the stability of aquatic ecosystems (Rahel and Olden 2008). We include simple methods that quantify the presence and abundance of a select list of invasive taxa developed with park staff. These methods should not replace more specific protocols that may be implemented by a park or other collaborators for other or more specific purposes.

The Montana Department of Fish, Wildlife and Parks (MT FWP) maintain a list of species of concern in the state (MT FWP 2012). Most of these taxa are vertebrates (that we do not collect) or plants (for which we use alternate citations, see below). Invasive aquatic invertebrates on the list include the zebra and quagga mussel (*Dreissena polymorpha* and *Dreissena rostriformis*), the New Zealand mudsnail (*Potamopyrgus antipodarum*), and the rusty crayfish (*Orconectes rusticus*). All of these species could potentially occur in the Little Bighorn at LIBI, although it is currently not ideal habitat for the mussels and may not be for the crayfish. Another important species of concern (although not on MT FWP list yet) is the diatom *Didymosphenia geminata*, commonly referred to as didymo or rock snot. The Little Bighorn at LIBI is not likely viable habitat for didymo. However, we will still monitor for its presence in our samples as there are locations higher in the watershed that are suitable habitat and the species has displayed a tendency to be highly invasive and adapt to diverse habitats.

Riparian corridors are often ideal habitat for invasive plants. These species may have impacts on community structure and can alter soil and water chemistry. Moreover, invasion into riparian areas is often a useful indicator of general disturbance (often anthropogenic at least in part). Target invasive plants were developed in concert with staff from all ROMN parks. These lists include taxa that are ecologically varied, easy to identify, truly invasive, ecologically or economically intrusive, and some of which are also included in regional surveys like EMAP (Ringold et al. 2008).

Monitoring Objectives

The general goals for long-term ecological monitoring of the Little Bighorn at LIBI focus on documenting the status and trend in condition, understanding the causes of change in condition, and assisting in the application of SEI results and relevant auxiliary information to resource management. Statistically rigorous estimates of trend are likely possible after five cycles of sentinel data collection have been completed at a sentinel site. Simpler estimates of change are conducted after the first two to four cycles.

1. Determine the condition (status) on five-year intervals of the Little Bighorn at the LIBI sentinel site using bioassessment (macroinvertebrate and diatom assemblages), physical habitat, and water/sediment physiochemistry.

2. Determine the percent change in the condition of select responses detailed in objective 1 after the 2nd-4th cycle of sampling.

3. Determine the long-term trend in the condition of select responses detailed in objective 1 after the 5th and each subsequent cycle of the sampling.

4. Determine long-term trends in select water physiochemistry at the nearby upstream USGS gauge near Hardin, Montana.

5. Relate any spatial or temporal patterns (including trend when possible) in select responses detailed in objective 1 to important ecological and anthropogenic drivers.

   These models depend on scale appropriate covariate SEI and auxiliary data, with clear (and often causal) connections to SEI responses and are therefore done on an as possible basis.

6. Assess these responses as follows:

   a. Compare to existing and published assessment points, including any regulatory criteria, ecological thresholds or ecoregion assessment points that are relevant to the Little Bighorn at LIBI and its management.

   b. Compare to ecoregion assessment points derived from distributions of reference site data from the surrounding ecoregion. These are developed for a subset of SEI responses based on data availability and quality and the relevance of the response to Little Bighorn management.

c. Compare to baselines derived from partner or auxiliary data or, after 5 repeated sample cycles, SEI data. These are developed for a subset of SEI responses based on data availability and quality and the relevance of the response to Little Bighorn management.

Several monitoring objectives specific to management needs at LIBI may be included, to varying degrees, within ROMN SEI monitoring as the protocol matures. The relevance of these to SEI monitoring and the capacity of the Network to successfully include them in the core SEI protocol will require careful consideration. The ROMN will work with park management to help interpret and apply SEI data to LIBI management needs. Likely applications include: understanding fire and grazing impacts in the riparian corridor, Great Blue Heron management, and interpretation of SEI data in the context of climate change impacts on stream flows, irrigation needs, and erosion.

Methods

The following sections present brief summaries of how and why sites were selected (sample design), why particular responses were selected and how data were collected in the field. For a complete description see Appendix A and the SEI protocol narrative and associated SOPs (Schweiger et al. In Review).

Sample Design

SEI data collection at LIBI occurs within an approximately 1,200 meter sample reach defined by series of subsample locations. The reach extends from the last meander bend of the river before it leaves the Custer Unit to near the middle of the Custer Unit (see Figure 2 and Figure 3). The sample design used in LIBI SEI monitoring was a hand-picked (not randomly selected) sentinel site approach (see Britten et al. 2007) for a complete overview of ROMN sample design strategies). This reach was selected largely for ease of access but also because it is typical opd the river as it flows through and along the park The ROMN currently does not sample any of the non-perennial tributaries that have a confluence with the Little Bighorn or any groundwater resources.

Because the sample reach was not selected at random, in a strict sense the inference of SEI monitoring results is limited to this reach or even select points within it. However, we are sampling a sizable portion of the river in the park (the total extent of the Little Bighorn within LIBI is only around 7.2 km, including both units) and we feel our sample reach is largely representative of this extent. Therefore, we generally interpret results at the scale of the park. We do include data on select drivers and covariates across larger scales as applicable to help understand SEI data in a larger context. This is accomplished largely through (1) analyses that include landscape-level and climatic drivers of stream condition and (2) our use of auxiliary data from other sources (especially the nearby USGS stream gauge in Hardin) that have a broader temporal and spatial extent and/or inference.

Temporal scales of inference may be more limited for many responses (especially chemistry) and may only represent conditions at the time of sampling. In addition, rare and short-term events such as floods typically are not captured in our water physiochemistry measures. However, water and sediment chemistry samples are routinely collected several times per year in order to build a database that represents the range of conditions that occur at the sampled site(s). Other parameters may be more readily inferred to a longer timeframe. Specifically, while biological responses are collected at base flow (as this is when most species are at a more identifiable life-stage and potentially more stressed by stream flow levels) these responses often integrate longer time periods (i.e., lifespans or the time required for an assemblage to develop).

Sample Events

Events at sample sites are of two types. First, full sample events typically include all methods (water/sediment chemistry, habitat, and biology) and are done at base flow, once per year. Second, sentinel sample events include only water/sediment chemistry. They are conducted on key limbs of the hydrograph (rising, falling, etc.). We generally conduct three sentinel events at each sentinel site per year (the main event at base flow also includes water/sediment chemistry).

Due to high flow and unsafe conditions in 2007, biological samples (macroinvertebrates and periphyton) were collected using an *ad hoc* arrangement of 11 subsample locations spread across a variety of macrohabitats within the LIBI sample reach. In 2009, safe conditions permitted us to conduct a complete sample event. Because many of the same methods (net mesh size, time of each sample, periphyton collection details, etc.) were used in these sample events, we feel that the samples are sufficiently similar and treat the two data sets equivalently in most interpretation. Because many of the same methods (net mesh size, time of each sample, periphyton collection details, etc.)

were used in these sample events, we feel that the samples are sufficiently similar and treat the two data sets equivalently in most interpretation.

Field Data

Stream monitoring methods are relatively well established and we draw upon this wealth of knowledge for the ROMN SEI protocol used in LIBI. All SEI laboratory methods follow standard and accepted protocols implemented by each individual lab and include detailed quality assurance and control methods. The application of a standardized monitoring protocol across sites facilitates comparison of streams and rivers within an ecoregion. Sources of SEI methods include the EPA Environmental Monitoring and Assessment Program (EMAP; Stoddard et al. 2005), Flathead Lake Biological Station (FLBS; R. Hauer, pers. comm. 2007), U.S. Forest Service (Heitke et al. 2011), NPS Water Resource Division (WRD; Irwin 2006), several USGS approaches (e.g., Fitzpatrick et al. 1998), and the Montana Department of Environmental Quality (MT DEQ 2012a). However, SEI methods are not perfect duplicates of any of these other protocols and there may be subtle or non-quantified artifacts from methodological differences in our data. Where we feel this might have a meaningful impact we qualify results as necessary.

The SEI protocol includes a broad spectrum of indicators to help evaluate the ecological integrity of the Little Bighorn (Table 2). We include measures of drivers (or stressors) and ecological responses, such that we may better understand the linkages between

Table 2. Summary of SEI field data.

Indicator Class	Summary	
Water and Sediment Physio-chemistry	In Situ	temperature (synoptic and continuous), water; oxygen, dissolved; ph; specific conductance.
	Major ions	alkalinity, dissolved; calcium, dissolved; chloride, dissolved; fluoride, dissolved; hardness , dissolved; magnesium, dissolved; potassium, dissolved; silica, dissolved; sodium, dissolved; sulfate, dissolved; total suspended solids.
	Nutrients	ammonia, dissolved; nitrite + nitrate, dissolved; nitrite, dissolved; nitrate, dissolved; nitrogen, total; orthophosphate, dissolved; phosphorous, total; carbon, organic, dissolved; carbon, organic, total; chlorophyll-a in periphyton; ash free dry mass in periphyton.
	Metals in water	aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, selenium, zinc.
	Metals in sediment	aluminum, total; arsenic, total; barium, total; beryllium, total; cadmium, total; chromium, total; copper, total; lead, total; iron, total; mercury, total; selenium, total; silver, total; zinc, total.
Physical Habitat	instantaneous q continuous q (from nearby USGS gauge) thalweg profile channel geomorphology woody debris tally channel dimensions substrate quantification fish cover riparian vegetation human influence assessment of channel constraint, debris torrents, and major floods	
Benthic Macro-invertebrates	reach-wide habitat (composited across systematic transect array) sample	
Periphyton	reach-wide habitat (composited across systematic transect array) sample	

these and help parks apply these results to resource management. Core indicators include multiple measures of water and sediment physiochemistry (i.e., nutrients, metals, temperature); physical habitat (i.e., substrate composition, riparian cover, channel geomorphology); and community level assays of two important biological assemblages, macroinvertebrates and algae. The latter provide an integrated aspect for assessing ecological integrity because these organisms respond to environmental conditions over time and space.

We present summaries of field data collection methods, details on instrumentation and brief justifications for the major responses we collect in Appendix A. The full protocol is in Schweiger et al. (In Review). We do include some detail below regarding auxiliary data harvested from other monitoring programs and applied to LIBI SEI data interpretation. *Readers unfamiliar with the SEI protocol or stream monitoring in general should review Appendix A. Subsequent narrative in this report assumes that the reader is familiar with basic stream monitoring methodology*.

Site Layout

The design of the sample reach in LIBI follows the EPA EMAP site layout (Peck et al. 2006) as modified by the ROMN SEI protocol (Figure 6). The main sample events at LIBI use the "boatable" or non-wadeable set of SEI methods (see Figure A22 in Appendix A). Eleven shoreline stations, used for physical habitat characterization and biological subsampling, are placed at equal intervals along the reach (120 meters apart following the thalweg). Samples of benthos, periphyton, and sediment are taken at each of these shoreline stations. Riparian plots measuring 10x20 m are established on the banks at each shoreline station (and on the opposite bank) for collection of riparian vegetation attributes. Finally, a thalweg profile is established in the deepest part of the channel along the entire sample reach. Water chemistry and stream discharge are collected at the downstream end of the sample reach. This sample reach length captures repeating patterns of local habitat structure and biological variability associated with riffle-pool structure and meander bend morphology in the Little Bighorn (see Kaufmann et al. 1999 and references within). This general site layout (or similar derivatives) is used by other long-term monitoring programs (state and federal).

Auxiliary Data

We use several data sets not generated within the SEI protocol to compare to LIBI data and enhance our ability to characterize the Little Bighorn at LIBI. We also develop assessment points used to informally interpret SEI results from some of these auxiliary data sets (see below). Most of these data come from monitoring efforts conducted by state and other federal agencies as described below. Future SEI reports will also include data from the National Rivers and Stream Assessment (NRSA) sampled in 2008 and 2009 (EPA 2007). Analytical methods, including assumptions within comparisons between SEI and auxiliary data, are summarized in a subsequent section.

Water Physiochemistry and Streamflow

The USGS gauge station 06294000 on the Little Bighorn River near Hardin has a large amount of high-quality data available from USGS (USGS 2012a). While there are some concerns with the distance of this site from LIBI, we elected to harvest, analyze, and interpret a large amount of data for this report. We use these data largely to assess trends. Water physiochemistry data were retrieved from the National Water Information System (NWIS) database for the Hardin station over variable periods of record from 1970-2011. This included 24 nutrient, trace element, and major ions parameters used by the USGS (generally for the same reasons as we do within the SEI protocol). Daily stream discharge from 1953 through 2011 was also acquired. Finally, we harvested episodic stream temperature data, collected annually every few months from 1969 to the present. Only data publically available and thus passing all USGS QAQC checks were used. However, following (Mast

2007) we elected to retain trace-element results although it is documented that dissolved concentrations in USGS samples collected prior to 1992 may have been contaminated during sample collection and processing (USGS Office of Water Quality Technical Memorandum 91.10; USGS 2012b).

The NPS WRD ran a stream gauge at LIBI for water years 1999 to 2006. The NPS gauge, while not contemporaneous with SEI monitoring in the park, generated daily stream discharge and water temperatures (vs. the episodic temperature readings at the gauge near Hardin). As of 2012, NPS WRD considers the discharge data provisional and we therefore only use these data in comparison to the USGS gauge at Hardin to establish the validity of applying the USGS data to LIBI. However, we do directly use

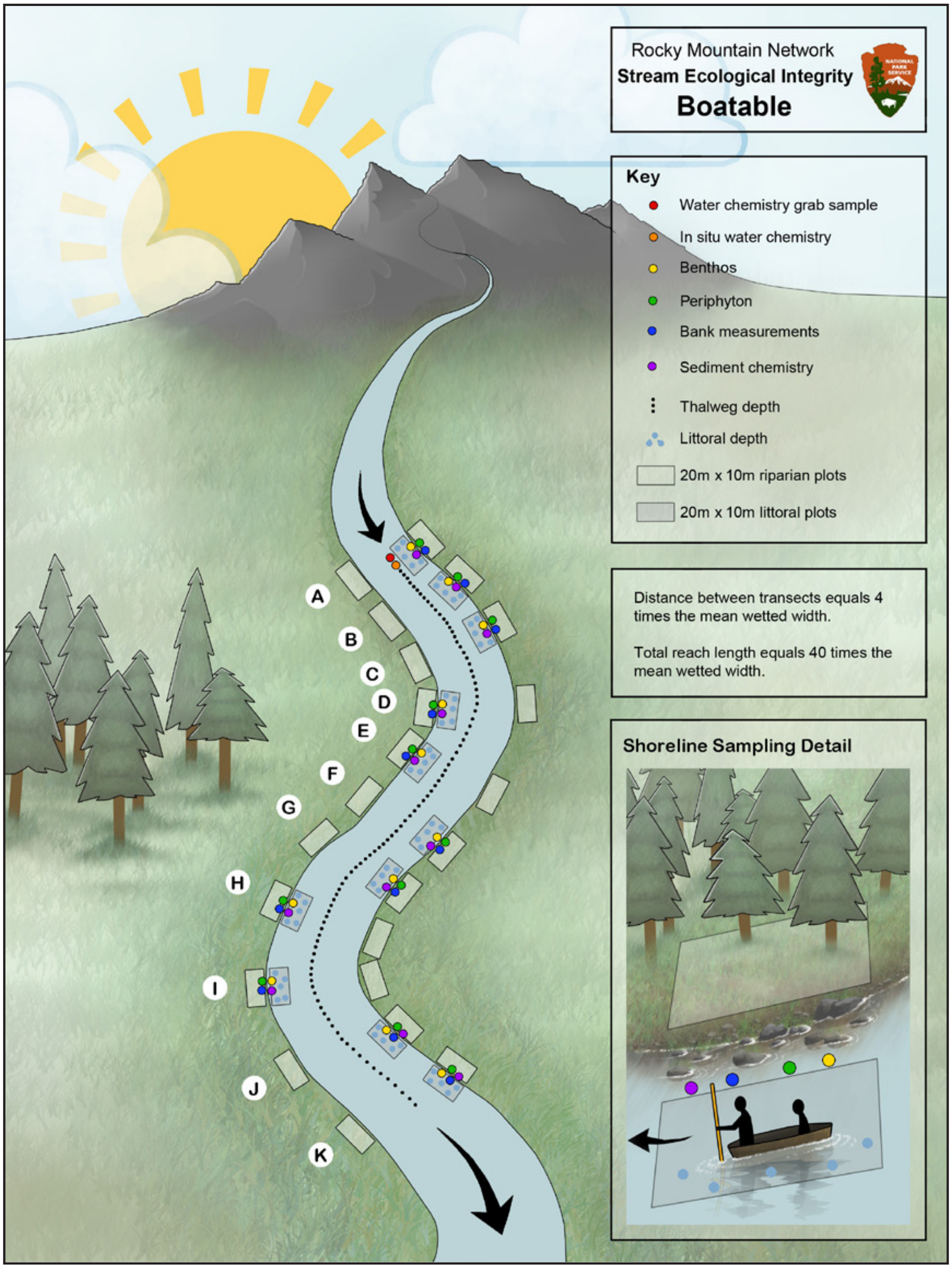


Figure 6. ROMN SEI non-wadeable sample reach in oblique profile. Stream flow is from the top to bottom of the figure. Sub-sample locations, riparian plot, and thalweg profile are all shown. Inset picture shows select details for shoreline sampling.

and interpret temperature data from the NPS gauge as WRD considers these data appropriate for our purposes.

We also used grab sample water chemistry data collected from 172 sites (38 degraded, 38 reference, and 96 with unknown or intermediate condition) sampled as part of the EMAP Western Pilot Project (Stoddard et al. 2005) from 2000 to 2004 within the Northwestern Great Plains ecoregion (Figure 7, in part). Note that the specific sample size available from these data sets for a given parameter varied and are listed with results given below. Chemistry methods used by EMAP were nearly identical to those within the SEI protocol. We did not restrict chemistry data to the state of Montana because assessment points we develop from these data are informal, are not used by MT DEQ to assess water quality and our source data were not restricted to Montana (like some of the biological data sets described below are). Rather, we used sites from the complete ecoregion, regardless of what state the site was in. This included sites in Montana, North/South Dakota and Wyoming.

Biological

For biological data (in this report, limited to macroinvertebrates) this includes (Figure 7): 28 sites (3 degraded, 9 reference, and 16 with unknown or intermediate condition) sampled as part of the EMAP Western Pilot Project (Stoddard et al. 2005) from 2000 to 2003, 18 sites in larger rivers similar to the Little Bighorn (1 degraded and 17 with unknown or intermediate condition) sampled by MT DEQ from 2001-2005 (Bollman 2006), 45 (all reference) sampled by the state as part of an on-going reference project (Suplee et al. 2005), and 34 sites (19 degraded, 13 reference, and 2 with unknown or intermediate condition) sampled from 2000 to 2003 by Utah State University as part of the EPA Science to Achieve Results (STAR) program (Hawkins et al. 2003). Five of the sites are treated in multiple sources (i.e., a few EMAP are also MT DEQ reference sites) reducing the total unique sample size compared to LIBI SEI data to 120. Specific sample sizes available from these data sets for a given metric varied and are listed in the results section below. Field and analytical methods for these programs were largely comparable to SEI protocols. To be included, external source data had to be from the Northwestern Great Plains ecoregion in Montana, have a multi-habitat sampling method, (for benthos) a minimum 300 organism lab count (for SEI we count at least 600), and a minimum of genus-level identification of insects, (including Chironomids). Jessup et al. (2006) and MT DEQ (2012a) show that, for at least the current bioassessment tools used in this report, models using MT DEQ or EPA (on which the SEI protocol is based) methods result in similar interpretations. We restricted auxiliary biological data to sites in the state of Montana because much of the source data were only from Montana streams and rivers.

Habitat

We used habitat data (Figure 7, in part) from 172 sites within the Northwestern Great Plains ecoregion (38 degraded, 38 reference, and 96 with unknown or intermediate condition) sampled from 2000 to 2004 as part of the EMAP Western Pilot Project (Stoddard et al. 2005). Note that the specific sample size available from these data sets for a given parameter varied and are listed with results given below. Habitat data collected by the EMAP program used a near identical field and analytical protocol as the SEI protocol. We did not restrict habitat data to the state of Montana because assessment points we develop from these data are informal, are not used by MT DEQ to assess stream condition and source data was available from a larger region (unlike some of the biological data sets described above). Rather, we used sites from the complete ecoregion, regardless of what state the site was in. This included sites in Montana, North/South Dakota and Wyoming.

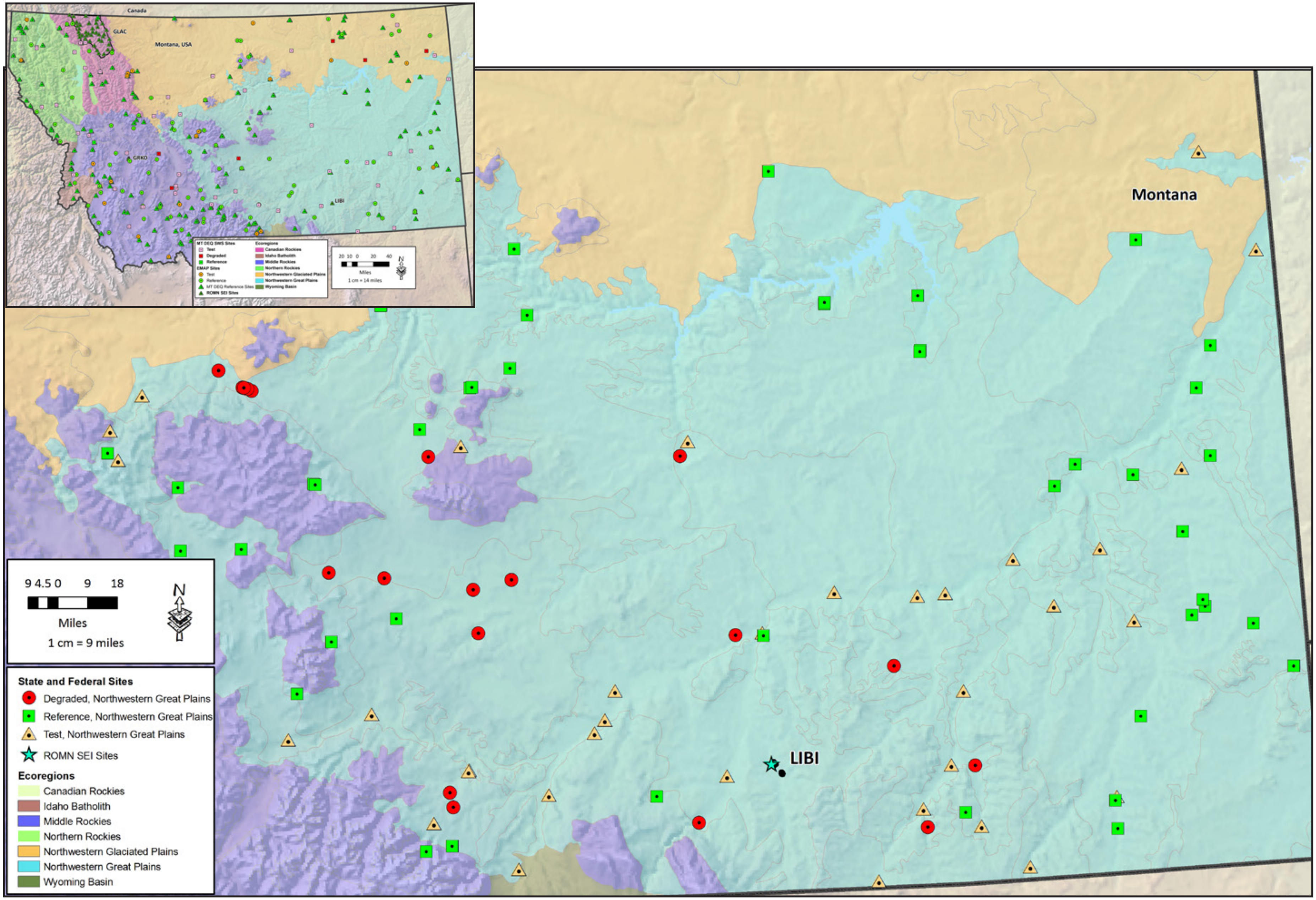


Figure 7. MT DEQ, EPA, and STAR monitoring sites in the Northwestern Great Plains ecoregion within Montana as used in comparison to select ROMN SEI results for LIBI. Sites are classified as reference, degraded or unknown (by the programs responsible for each site) with green showing reference sites, red degraded sites, and orange unknown ("test") sites. Inset shows all sites across the state with symbology based on the source program of each site. Note that additional sites in the ecoregion but outside of Montana are not shown here were used for select habitat and chemistry parameters.

Analyses

The following sections present summaries of how LIBI SEI data were analyzed and interpreted (for complete descriptions see Schweiger et al. In Review). We first describe the statistics and models we use to estimate the status (single point in time or summaries over very short time periods) in the condition of the Little Bighorn River during 2007-2010. We then summarize how we estimate trend in condition (for now, only using auxiliary data from the USGS gauge). Next, we summarize how these results are interpreted or assessed. Importantly, we use multiple approaches to interpreting SEI data including a broad spectrum of current and historic metrics, informal comparison to regulatory criteria (because NPS is not the ultimate regulatory authority for water bodies in LIBI or any NPS unit), and derivation of and then comparison to unique or proprietary criteria. Our approach to interpreting results is different from what regulatory agencies like MT DEQ or EPA might employ. It is in keeping with the NPS mandate to manage ecosystems within parks following NPS guidance and the founding purpose of LIBI. We are careful to qualify these methods and to distinguish them from more formal treatments by regulatory agencies. Finally, we present how we assess the quality of SEI data and how we apply information from similar monitoring (Stoddard et al. 2005) that may roughly approximate the precision of some of the indicators used at LIBI.

Status

We estimate status using simple descriptive statistics of core SEI responses or various modeled metrics derived from raw data. Results are presented within tables and through a variety of graphics. For some responses, we do not have either spatial or temporal replicates and so we cannot yet report estimates of variance.

Water and Sediment Physiochemistry

For synoptic or instantaneous in situ and grab samples of water physiochemistry we report a minimum, maximum, and median value summarized across all events during 2008-2010. We use a median (rather than a mean) because of lower bounds of zero, censored or imputed non-detect values, outliers and the often very skewed distributions typical of these data (Mast 2007).

Analyses of water chemistry samples by laboratories often include “non-detects” or values below the ability of a given lab’s capacity to accurately resolve (see Appendix G for laboratory detection limits). These present challenges for analyzing and interpreting data. We use a regression on order statistics (ROS) imputation method from Helsel (2005) for all censored lab data. The ROS method resolves nondetects on the basis of a probability plot of results that were detected from a larger dataset. It allows multiple detection limits for a parameter within a single data set. We used all data within the ROMN SEI database (i.e., including data from GLAC and GRKO) to better estimate the nondetect values (note our summary statistics presented here are only based on LIBI samples).

<u>Stream Temperature</u>

Stream water temperature data are available as a (nearly) continuous daily time series from the USGS gauge in Hardin from 1972 to 2010, the NPS WRD gauge from 2002 to 2011 in the park and from SEI loggers from 2007 to 2010. We present a subset of these data using time series plots by water years from 2001 to 2010. To help understand simple patterns in these data relevant in their interpretation as a baseline, we compare temperature and USGS discharge from the Hardin or NPS WRD gauge using a simple no-parametric correlation. We restrict data in these models to spring and summer (March 1 through August 31) to focus on patterns in ecologically more relevant runoff through base flow portion of the hydrograph. In addition, various intervals of temperature data from these loggers are used to (1) estimate potential baselines for comparison to future stream temperatures, (2) explore short term patterns in the phenology of freeze-thaw cycles, and

(3) estimate seasonally-adjusted models of trends in water temperatures (further described in the section below on trend analyses).

We estimate mean August stream temperature as a possible baseline statistic using daily values at the NPS WRD gauge (2001-2007) or the SEI logger (2010 and 2011) and qualitatively interpret patterns in this measure across the period of record. We use August temperatures because this is generally the hottest month of the year and may be when warming trends are most evident as climate regimes shifts over time. However, the choice of a specific temperature statistic to use as a baseline is complex and we are exploring alternatives (Dettinger et al. 2004, Isaak et al. 2011, Arismendi et al. 2012) including mean or maximum mean spring water temperatures (as a seven-day rolling average of daily data; Isaak et al. 2011) which may also be useful given shifts in runoff and other aspects of a streams hydrograph with changing climate.

We summarize the phenology of freeze-thaw cycles by estimating the last (or a thaw) and first day of freezing in each water year. We define a thaw or freeze as any period of 2 days or more with temperatures above or below 0.5°C. We compare these dates across ad hoc historic (xxx) and current time periods (current begins with SEI monitoring in 2008) using non-parametric Kruskal-Wallis tests.

Physical Habitat

Habitat Metrics

The large number of raw physical habitat measures collected during a full SEI sample event are summarized into over 30 synthetic metrics and expressed at the sample reach scale. SEI habitat sampling within a reach is systematic and this feature lends itself to calculating representative summaries of the habitat characteristics of the sample reach. Habitat metrics include simple summaries of raw data, areal cover estimates from cover class data, proximity weighted estimates, and more detailed specific approaches for calculating woody debris abundance, residual pool characteristics, sinuosity, and bed stability. Over 100 habitat responses collected in the field are reduced to dozens of metrics. Using guidance in Kaufmann et al. (1999) and Stoddard et al. (2005), we further reduced the set interpreted here to 33.

At the time of this reports creation we only had a single full sample event (in 2009) that included habitat. Therefore, we can only report single values for habitat metrics and until we accrue more habitat data we have no estimates of the spatial or temporal variability in habitat structure at LIBI (some metrics are expressions of within reach spatial variance in a habitat response as measured during a sample event). However, as discussed below, we do include estimates of signal to noise (S:N; Kaufmann et al. 1999) in each metric using 2000-2004 EMAP data from across the Northwestern Great Plains ecoregion (Stoddard et al. 2005). These provide some context for how variable each metric is over space and time. This improves our ability to interpret habitat condition as well as offer insight into which metrics perform the best. Given the near identical habitat methods within the SEI and EMAP protocol these values do provide a sense of how variable each metric is across the ecoregion and provide some context for the LIBI SEI results.

Hydrology: Stream Flow

Using the Climate Data Summarizer (version 3.4; Walking Shadow Ecology 2012) we create hydrographs by water year with data from the USGS gauge in Hardin from 2007-2010. We do not present annual hydrographs for the data from the NPS WRD gauge in LIBI as of 2012 these data had not been released by WRD for this purpose. We do use the WRD data to compare to the USGS Hardin gauge data to determine how well data from the somewhat remote gauge might be describing stream flow patterns in LIBI. The hydrographs include discharge during the water year, the median discharge over a 30-year period of record (1980-2010) from the USGS Hardin gauge, and the midpoint of the annual discharge for these two time intervals. We summarize the total discharge across each water year, including maximum flow, the date of maximum flow, annual median flow, and its standard deviation. Finally, a statistical analysis of annual peak flow data from the period of record for the Hardin gauge was performed using Hydraulic Engineering Center-Statistical Software Package (HEC-SSP) 2.0 (USACE, 2010). This tool generates recurrence intervals (from 1 to 500 years, also known, for example, as a “100 year flood event”), and the range in probabilities (from 0.2 to 99) of exceeding the annual peak streamflow.

Biology

Bioassessment

The primary way in which we analyze biological data is via assemblage or community-level metrics generated from bioassessment models. This follows a long tradition in stream monitoring and assessment (e.g., Kolkwitz and Marsson 1908) known as bioassessment (Barbour et al. 2000). Bioassessment assumes that the composition of biological communities reflects the overall ecological integrity of a system. Evidence suggests it may detect stressors that other approaches fail to reveal (Karr and Dudley 1981, Karr and Chu 1997).

MT DEQ and other ROMN partners have developed a variety of bioassessment models to help monitor stream and river condition over the last two decades and we use a subset of these (Table 3). We emphasize models used by MT DEQ (as of 2011) given their higher levels of precision. However, we feel that many older metrics or those that may be more regional in scale have general interpretative value for our purposes, and we include select examples of these in this report. Where useful, we do include interpretation of individual taxa (i.e., invasive species or taxa that are indicative of a particular aspect of stream condition).

For benthos, we focus on two approaches: First, we derive scores using various iterations of a Multimetric Model (MMI; also known as an Index of Biotic Integrity). MMI models combine multiple characteristics of a macroinvertebrate assemblage that change in some predictable way with increased human influence that alters environmental conditions. They have a long history of successful use in bioassessment (however, beginning in 2012 Montana DEQ no longer employed a macroinvertebrate MMI in biological assessments). We include component metrics of the most current MT DEQ MMI to aid in its interpretation. Second, we apply the 2011 version of the MT DEQ River Invertebrate Prediction and Classification (RIVPACS) modeling system. RIVPACS models are calibrated with observations made at reference-quality sites across a region and the models relate taxon occurrences to multiple environmental gradients. In effect, the approach simultaneously models the niche relationships of many taxa and predicts the specific taxa that should occur at a site given its natural (i.e., reference) environmental characteristics. We estimate and interpret two statistics from RIVPACS, the simplest being the ratio of Observed to Expected taxa and the second a Bray-Curtis dissimilarity score. Note that MT DEQ uses the term “Observed/Expected models” to describe their use of RIVPACS but we elected to retain the more general name “RIVPACS” given our derivation of multiple statistics from the model.

For diatoms, we use two approaches: increaser models and a suite of individual metrics that describe specific aspects of community structure. Diatom increaser models summarize the relative abundance of diatom taxa that, as a group, exist in detectable amounts and demonstrate a meaningful, measurable, and significant response to specific stressors (sediment, nutrients, or metals). For additional details on these models see Appendix B and Schweiger et al. In Review).

Trend

Given the short time the SEI protocol has been implemented at LIBI, we cannot perform any meaningful trend analyses *with SEI data*. When we have a sufficient record (another 3-5 years), many of the response measures and metrics detailed above will be analyzed using trend models. USGS data from the nearby gauge near Hardin do allow select trend models as summarized below.

Table 3. Summary of 19 core SEI bioassessment metrics and rubrics for their interpretation. As discussed in text, both current and historic models are used.

Metrics	Range and Interpretation
Macroinvertebrates	
Low Valley Multimetric Index	0 - 100; low values suggest lower stream integrity
RIVPACS (O:E)	0 - 1+; low values suggest lower stream integrity
RIVPACS (Bray Curtis dissimilarity)	0 - 1+; high values suggest lower stream integrity
Plains Multimetric Index (classic)	0 - 100; low values suggest lower stream integrity
Karr Benthic Index of Biotic Integrity	0 - 100; low values suggest lower stream integrity
Hilsenhoff Biotic Index	0 - ~10; low values suggest higher nutrient conc.
Fine Sediment Biotic Index	0 - ~10; low values suggest more fine sediment
Temperature Index	0 - ~20; low values suggest colder stream temp.
Metal Tolerance Index	0 - ~10; low values suggest higher metal concentrations
Component metrics in current MMI	
EPT* Taxa Richness	0 - 100; low values suggest fewer EPT taxa
Percent Tanypodinae	0 - 100; low values suggest lower %
Percent Orthocladiinae of Chironomidae	0 - 100; low values suggest lower %
Predator Taxa Richness	0 - ~15; low values suggest fewer predator taxa
Percent Filterers and Collectors	0 - 100; low values suggest lower %
Diatoms	
Sediment Increasers, Warm Water	0 - 100; low values suggest a lower probability of sediment problems
Nutrient Increasers, Warm Water	0 - 100; low values suggest a lower probability of nutrient problems
Shannon Diversity	0 - ~5; low values suggest lower diatom diversity
Siltation Index	0 - 100; low values suggest less sediment
Pollution Index	0 - ~15; low values suggest lower nutrient concentrations

*EPT = Ephemeroptera, Plecoptera, and Trichopetera (families of macroinvertebrates)

Water Physiochemistry

We use the Estimate Trend (ESTREND; Schertz et al. 1991, Slack and Lorenz 2003) model to estimate long-term trend in select water physiochemistry at the Deer Lodge USGS gauge. ESTREND is a regression model that computes a trend (slope), which represents the median rate of change in concentration or discharge for the selected period of record. Following USGS convention, trends were considered statistically significant at the 0.1 probability level. The model uses nonparametric seasonal Kendall tests or a parametric Tobit model to account for variation across time due to season. The specific number of "seasons" for a parameter is determined by pattern in and the density of data (typically there are 4 to 6 seasons in most water chemistry parameters). The models may also use daily mean discharge to adjust for flow-related variability if the concentration-discharge relationship is significant (at the 0.10 probability level and if less than five percent of the data were censored). A model selection procedure was used to select the specific form of the flow adjustment model used. Incorporating flow in ESTREND not only improves the power of the statistical test, but decreases the possibility that an observed trend is an artifact of discharge (Hirsch et al. 1982, Schertz et al. 1991). The statistical methods used in ESTREND overcome non-normal and seasonally varying data with missing, censored values, and outliers, all of which adversely affect the performance of conventional statistical techniques. We include simple scatterplots of select responses over the period of record at each gauge to help visualize any pattern.

Assessment: Reference Condition, Assessment Points, and Interpretation

A key step in the analysis and reporting of

SEI data is interpreting the *meaning* behind an estimated result or set of results. For Example: Is a result suggestive of high-quality condition and why? Does a trend in a response suggest that condition is moving toward a non-reference state, and why? Clearly, this is a critical aspect of a mature long-term monitoring program and something the ROMN stresses. We do not want to merely collect data and report numbers, rather we seek to, in concert with ROMN park staff and other partners, include management relevant interpretation in the reporting of our monitoring results.

The ultimate goal of any ecological monitoring effort is to understand the ***condition*** or quality of an ecosystem or some resource of interest at a defined spatial (e.g., a single site or an entire park) and temporal (e.g., once or over time) scale. Ecological condition is influenced by both anthropogenic and natural drivers, and thus occurs as a distribution or gradient of states. For most resources, the distribution of condition levels ranges from some dysfunctional, aberrant or "non-natural" state to a functional, intact, or "natural" state. If assessed over a constrained time period (e.g., once), condition can be expressed as the ***status*** of the ecological resource of interest. If assessed over time, it may be expressed as a ***trend*** (which might have a value of zero, indicating no trend). ***Indicators*** or ***vital signs*** are components or elements of an ecological resource of interest that are particularly information rich and that represent or indicate condition. ***Measures*** are specific, often field-based, measurements used to quantify or qualitatively evaluate the condition of an indicator at a particular place and time. Measures are never perfect and the inability to measure or quantify condition exactly adds additional variance to the characterization of condition.

We generally follow approaches and use terminology as presented in Stoddard et al. (2006), Bennetts et al. (2007), and Hawkins et al. (2010) as these methods have become well established in other federal monitoring programs, they are used in part by the State of Montana (Suplee et al. 2005) and are beginning to coalesce within the NPS.

Reference Condition

Ecological assessments, directly or indirectly, compare measures of indicators of the status of condition or trend in condition to some comparative condition state or rate of change in this state. Usually, this is a condition in the absence of human disturbance, or the "natural state" (Steedman 1994, Hughes 1995, Jackson and Davis 1995, Davies and Jackson 2006) and is described as the ***reference condition*** (Karr and Chu 1999). Importantly, the reference condition is a gradient or distribution of values as a broad spectrum of natural ecological drivers such as climate, geography, or successional dynamics that have led to natural variation in condition.

Reference condition has been used in ecological assessment in at least four different ways (Stoddard et al. 2006):

1. the condition of ecosystems at some point in the past;
2. the condition that might be achieved if resource management was more effective;
3. the best existing condition; or
4. the condition of systems in the absence of significant human disturbance.

The current NPS I&M treatment (S. Fancy, pers. comm. November, 2013) defines a reference condition as a quantifiable or otherwise objective value or range of values for an indicator of condition that is intended to provide context for comparison with current condition. Furthermore, NPS considers the reference condition to represent an acceptable resource condition supported by appropriate information and scientific or scholarly consensus. This is a general definition and allows any of the four forms defined by Stoddard et al. (2006) listed above. However, a specific and operational definition of reference condition is important for application in ROMN SEI monitoring at LIBI. For example, a reference condition estimated as the condition of ecosystems at some point in the past is very different from a reference condition estimated as the condition that today's sites might achieve if they were better managed. Moreover, these two types of reference conditions (historic and future or desired with ideal management) may be difficult to numerically estimate.

The ROMN has elected to use two forms or definitions of reference condition, depending on which ROMN park is being evaluated. First, for our wilderness parks (Glacier, Rocky, and Great Sand Dunes National Parks), we use a ***minimally disturbed condition*** (MDC) or the best existing condition. Park management at GRKO also elected to use a MDC approach. Second, for LIBI, nested within a more anthropogenic landscape, we use a ***least disturbed condition*** (LDC) or a condition defined by the absence of significant human disturbance. We define these further below.

A MDC or LDC as a distribution of numeric estimates of condition can be empirically derived from ***reference sites*** or stream sites independently determined to be in a MDC or LDC state. The process for evaluating candidate sites to determine their condition state can be complex (Stoddard et al. 2006). In summary, samples of candidate reference sites are generated from large unbiased surveys of a parks streams or from representative samples of streams in the ecoregion(s) in which a park is located. Reference sites are derived from these samples using a series of filters or models that cull sites that are above relevant criteria or other assessment points (see below). The assessment points used for this filtering are non-biological and are usually water chemistry criteria, the density or simple presence of anthropogenic disturbances (i.e., a coal mine) in a streams watershed or general large-scale land-use patterns (e.g., the proportion of a sites watershed that is logged).

The MDC describes a state in absence of significant human disturbance, or a condition that is the best approximation or estimate of ecological integrity. However, reference sites truly or completely unaffected by the global influence of human activity do not exist. Therefore, minimal disturbances are allowed (e.g., atmospheric contaminants at levels below known effects). Once established, the distribution created by a group of reference sites in MDC will vary little over time. Long-term climatic, geologic, and ecological fluctuations will inevitably change the characteristics of individual sites within this distribution, but the range of MDC should be nearly invariant, and its distribution can serve as an anchor by which to judge current condition.

An LDC describes the best available condition within a landscape. It is based on a set of explicit rules that allow a degree of human activity (Bailey et al. 2004, Hughes et al. 1986, Hughes 1995). These rules vary from region to region, given the characteristics of the landscape and human use of the landscape and are developed iteratively with the goal of establishing the least amount of ambient human disturbance in the region under study. Because the degree of human disturbance changes over time (i.e., as either degradation or restoration occurs), the LDC may also vary with time—this must be carefully considered in assessing monitoring data.

Assessment Points

While a reference condition is important, or even required for some approaches to assessment (see below), most interpretations about status or trend in an ecological response are made relative to single parameters (or a discrete range of values) that define boundaries between condition states. In the simplest case, these boundary values are compared to monitoring data and an assessment is made as to whether the monitoring data is in ***reference***, ***intermediate***, or ***non-reference*** (more complex methods may use the complete reference condition distribution for comparison and/or statistical methods to attach a probability to these statements). The type, form and estimation methods behind these boundaries have been variously presented in the literature. Bennetts et al. (2007) provide a useful summary relevant to NPS I&M monitoring and proposes that the term ***assessment point*** be used as a catch-all term and as a way to more explicitly connect monitoring, assessment, and park resource management. Assessment points represent points along a continuum of condition states where scientists and park managers have agreed that assessment of the status or trend of a resource relative to program goals, natural variation, or potential concerns is warranted. These points may take the following form:

Assessment points may be true ***ecological thresholds*** where abrupt change occurs in ecosystem condition (Groffman et al. 2006). Ecological thresholds can be particularly important as there are sometimes irrecoverable consequences to crossing them (Groffman et al. 2006). Examples in stream ecosystems relevant to ROMN parks might include heavy metal concentrations driven by mine drainage that can often dramatically and potentially permanently alter communities of macroinvertebrates and diatoms (Clements et al. 2000, Kashian et al. 2007). Many examples exist in the terrestrial ecosystems such as fire-type systems being invaded by annual grasses (Bestelmeyer 2006, Briske et al. 2006, 2008). However, despite widespread agreement among scientists that ecological thresholds are real and can be extremely important, they are often difficult to estimate as they can be influenced by multiple complicating factors (Lindenmayer and Luck 2005, Groffman et al. 2006). Ecological thresholds often require complex modeling and rich data sets to estimate and describe causal relationships among ecological response and system drivers. Assessment points set at an actual ecological threshold may run the risk of not allowing sufficient time for management actions to avoid a park resource becoming degraded beyond repair. However, if the system dynamics around threshold are understood, assessment points at ecological thresholds may afford management clear direction in where or how to manage a system because of the possible strong behavior when systems trend near these proverbial cliffs.

Many monitoring programs derive assessment points from distributions of an indicator created from a sample of LDC or MDC reference sites (Stoddard et al. 2005, Suplee et al. 2005, CO DPHE 2010). We use the term ***ecoregion assessment points*** for these boundaries as in many cases the reference distributions used are from a sample of reference sites from an ecoregion (although in ROMO or GLAC we might also or instead use data from our extensive unbiased surveys of the parks streams). Most current programs simply choose a percentile from the MDC or LDC reference distribution as the assessment boundary (Stoddard et al. 2005). In most cases, these percentiles are less conservative in LDC, allowing a more disturbed ecoregion assessment point that is in a sense more realistic in these landscapes. While these percentiles are arbitrary, because they occur within a well-defined reference condition distribution and are explicit, they have value, especially when used over time. Other methods for locating these boundaries may also be employed that model the relationships between response and disturbance at reference sites (Schoolmaster et al. 2012, 2013a,b), and thus might estimate more meaningful ecological patterns, perhaps even a true ecological threshold. Ecoregion assessment points figure prominently in ROMN interpretation of monitoring data at LIBI.

A similar type of assessment point can be generated from time series data and function as ***baseline assessment points*** or more traditionally just ***baselines***. These may be simple summary statistics derived from a sufficient record of data or more complex trend model parameters. The type of data used in estimating the baseline value determines much about the quality and form of the assessment point. If the source data are from a well-designed survey of an entire resource sampled over time they likely have more value than if from a single site that may not be representative of the resource of interest. Similarly, if the source data span a long time period that captures relevant temporal dynamics they are likely more representative than if the data came from a single sample event. Baselines may be true ecological thresholds if they are generated from models that include sufficient covariates to estimate causal patterns in the response of interest. Alternatively they may be somewhat arbitrary (but if derived from a sufficient period of record likely represent a meaningful estimate of the state or trend in a response).

Criteria (also called standards) are assessment points defined for decision that have an explicit connection to a regulatory policy. These are usually based on human health or environmental effects and generally represent the lower limits of the acceptable range in a condition gradient (or the boundary of non-reference) and are used by regulatory agencies to ensure that a resource does not become impaired. Water quality criteria are well-known examples. Criteria are often estimated using experimental methods (i.e., finding the lethal dose of some chemical) but can come from modeling as well. The NPS defines and uses criteria internally as an approach to facilitating decisions regarding the management of public use of parks (NPS 2005). The ROMNs use of criteria as assessment points is informal (i.e., as stated several times in this document, not legally binding), but in some cases these values connect our assessment to a rich history of monitoring by regulatory agencies such as MT DEQ or the U.S. EPA.

Finally, ***management assessment points*** represent a point or zone that triggers management action within a given context. Management assessment points are often set to facilitate *a priori* consideration of undesirable ecosystem changes (e.g., ecological thresholds) and enable more proactive management responses. This is complex as it requires knowledge of the rate of change in a system (so the ***tipping point*** at which a system first begins to change is knowable), the response time required for management to change system behavior, and monitoring keyed into these temporal dynamics to inform management of success (or not). Ideally, management assessment points include all the factors that management decisions must be based on such as social, economic, and political values but this of course adds to the complexity and may be part of the reason management assessment points are somewhat rare in practice (Bennetts et al. 2007).

Several other forms or definitions of assessment points exist in the literature and in practice within monitoring and assessment programs (i.e., critical loads, desired future conditions, threshold of potential concern; Bennetts et al. 2007). However, as of this documents publication, we focus on ecological thresholds (where possible), ecoregion assessment points, baselines, and criteria. Management assessment points are also important but these should be set by park resource managers (ideally in consultation with the ROMN and other collaborators) and this was under development.

ROMN Assessment Process at LIBI

In broad stroke, we compare our monitoring results to established numeric water quality criteria (as defined by the State of Montana, EPA, or in the future the Crow Nation), relevant published assessment points (that may not be used by a State) including ecological assessment points (published or derived by the ROMN), or to baselines from SEI or other data. We use numeric (versus narrative) assessment points to remove as much subjectivity from the process as possible. We interpret these comparisons using ecological theory, NPS I&M Division guidance, NPS resource management policies, and collaborative work with ROMN partners, especially park staff and management. As noted above, we use the terms reference, intermediate and non-reference to label condition states or how a SEI response relates to an assessment point.

In LIBI, given a non-pseudoreplicated or temporally auto-correlated sample size of one and various statistical issues with assessing single sites (Hawkins et al. 2010), we do not perform statistical tests that compare SEI data to assessment points; all comparisons are qualitative and are simply whether a SEI value during a defined time period, is above or below a assessment point, with no estimate of the statistical probability of this occurrence. As we collect additional SEI data at LIBI we will explore more rigorous methods. In GLAC and ROMO, with well-designed surveys and large sample sizes a much broader array of statistical tests are available. The appropriate hypothesis when statistically assessing individual sites or a population of streams is whether the condition observed is outside the range of values expected among an appropriate set of reference sites (Smith et al. 2005, Bowman and Somers 2006, Hawkins et al. 2010).

Note that in most cases MT DEQ, when exercising their regulatory authority, does not simply designate a stream as impaired if a parameter is above a criterion once (with an exception for human health criteria). For example, in nutrient assessment a number of exceedances are allowed over well-defined time period and spatial extent before the state would designate a site as impaired. Suplee and Suplee (2011) present details on nutrient assessment in Montana, including statistical tests used to establish an actual impairment.

We occasionally apply multiple assessment points to a single response indicator or its measure. This is appropriate when alternate assessment points are derived from data at different scales or when one describes an ecological response and one a strictly regulatory perspective. When results using different assessment points disagree or when general conclusions differ across indicators (e.g., water chemistry suggests a site is in a reference state, but its biology does not), we use a weight of evidence approach to help resolve overall stream condition; however, we do emphasize biological and habitat responses as these are often more synthetic or integrative vital signs. Disagreement in two or more SEI responses may reflect error in the methods or models used to create the metrics or collect the data. Alternatively, it may reflect the true nature of complex ecological systems; it is not unusual for one aspect of an ecological system to be intact and one to be in a non-reference state. Note that the "Summary Condition Table" presented in the Executive Summary of this report represent a weight of evidence approach to derive a general statement of condition, trend and confidence in these characterizations within major classes of response as used to characterize the condition of a ROMN park stream resource.

We do not restrict the indicators or metrics we use (and any assessment points created for these) to those currently employed by MT DEQ or the U.S .EPA nor do we purposefully restrict the number we use. Rather, we use a broad spectrum of models, indices, and metrics. We feel this is appropriate as it enables a more comprehensive perspective and connects SEI data to a larger array of historic and ongoing stream monitoring by ROMN partners. That said, we do emphasize approaches that states and other partners have demonstrated are more precise and predictive. We will also simplify the set of models used as we learn what works best over time.

Criteria

We harvest criteria from the most current sources available from the State of Montana (MT DEQ 2012e) or the U.S. EPA (EPA

Importantly, the NPS does not have regulatory authority over water quality in LIBI under the Clean Water Act, including the ability to evaluate beneficial designated uses. As noted above, the Organic Act and various NPS Management Policies do require park management to maintain, rehabilitate, and perpetuate the inherent integrity of aquatic resources and processes and NPS will work with appropriate State and other Federal partners to do so. SEI assessment at LIBI is conducted outside of any Clean Water Act motivated regulatory context. *Any comparisons we make to state, federal or future Crow Nation criteria do not include any official statement as to whether a beneficial designated use is attained.* NPS can participate in collecting data used in the protection of water bodies in parks under state jurisdiction through the Clean Water Act.

2009a.). Montana numeric water quality criteria are for potential effects of chronic exposure over an extended period of time (months) or for acute exposure over a short period of time (hours or days). Permitted levels are lower for chronic aquatic-life exposure than for acute exposure. Standards for chronic exposure may not be directly comparable to SEI results obtained from episodic or one-time grab samples and from a compliance standpoint, acute instantaneous criteria afford the only direct comparison for such data. However, from a resource-conservation standpoint, instantaneous grab-sample data, when compared against more stringent aquatic-life chronic criteria, can provide a means of early warning and an indication of a problem that may require more attention. For these reasons, we use aquatic-life chronic standards with the goal of providing advance warning of an impending problem before it becomes severe. This mirrors USGS protocols also applied to data from ROMN parks (Mast 2007).

Ecoregion Assessment Points

For LIBI, following park management guidance we develop a LDC from reference stream sites identified by MT DEQ (Suplee et al. 2005), U.S. EPA (Stoddard et al. 2005), and other partners within the Northwestern Great Plains ecoregion and estimate novel ecoregion threshold values within these distributions following methods in Hughes et al. (1986) and Stoddard et al. (2005). We accept the reference sites designation and methods used to reach these conclusions by Suplee et al. (2005) and Stoddard et al. (2005). Currently for responses that increase with decreasing condition we use the >75th or <50th percentile values for non-reference and reference (respectively). For responses that increase with increasing condition, we use the <25th or >50th percentile as thresholds for non-reference and reference (respectively). Note that these percentile values are less conservative and potentially more appropriate for the likely more degraded LDC typical in the Northwestern Great Plains ecoregion.

Assumptions

The estimation of ecoregion assessment points from ecoregion reference site data requires some important assumptions (Hughes et al. 1986, Hawkins et al. 2010). First, it assumes that there are no meaningful methodological differences in the protocols employed by the various programs that generate reference site data that would increase measurement error. We feel that this is not a prohibitive assumption for our purposes as in most cases the methods used in are derivatives of the U.S. EPA EMAP protocol and are quite similar. Jessup (2006) shows that stream monitoring data collected by several different programs in Montana, typically give comparable results, especially when using more derived models/metrics from a MMI or RIVPACS model.

Second, we assume ecoregion reference sites used to derive the MDC are similar enough to the Little Bighorn at LIBI such that they can be used as essentially replicates of fixed controls (Hawkins et al. 2010). The spatial variation among reference sites in a ecoregion (an outcome of multidimensional environmental heterogeneity that exists naturally across any landscape and its waterways) represents natural variation associated with water body types that occurs within the ecoregion—this is the primary reason why the suite of reference sites used are not restricted to identical or near-identical stream types as the site(s) being tested. The variation expressed by these distributions is constrained to a degree by the shared landscape context and geophysical drivers of stream sites within a common ecoregion (Hynes 1975). Hughes et al. (1986) suggests that the proximate environmental features common to ecoregions should strongly influence the biotic character of streams. Thus, ecoregions might partition (control for) the collective effects of the most important natural factors that influence the distribution and abundance of aquatic biota.

The assumption that ecoregion reference sites create a valid and useful context for comparison and interpretation of SEI monitoring data is fairly restrictive. However, the approach has been used for at least two decades by multiple agencies, has enabled effective ecological monitoring and resource management and we feel it is useful for understanding SEI data. In a sense to cover all the bases, we also use models (i.e., RIVPACS) that take an alternate approach and do not a priori assume reference sites are grouped regionally. Rather, given the well documented (Ostermiller and Hawkins 2004, Hawkins 2006, Ode et al. 2008) association of reference-site biota (and the indices derived from them) with natural gradients that transcend ecoregions or vary markedly within them RIVPACS uses biota-environment relationships derived from reference sites to predict the most likely ecological reference condition at any individual assessed site (Hawkins et al. 2010). Of note, in larger ROMN parks, with larger samples of independent sites we have been able to generate proprietary and novel MMI models that account for these gradients (Schoolmaster et al. 2012, 2013a,b), perhaps blending the best of these two approaches.

<u>Baselines</u>
For some indicators, we statistically summarize data collected at the beginning of SEI monitoring or use partner data from the USGS stream gauge near Hardin to estimate a baseline condition against which future or current status and trend might be compared. SEI derived baseline assessment points will require several monitoring cycles to have any confidence that they are estimates of a meaningful condition state. In most cases, determining whether a baseline assessment point occurs in the reference range of the condition gradient will require modeling. Until this is known, interpretation of comparisons of current condition to baselines or of any trend developed with the baseline as a starting point may only be relative in nature.

Summary

In summary, the key steps of our assessment methods at LIBI are as follows:

1. **Compare SEI data to existing published State of Montana criteria** (or in the future from the Crow Tribe or EPA) and interpret these comparisons. This is done for most water chemistry constituents and several MT DEQ biological metrics. If regulatory criteria exist we apply and interpret these values before other assessment points as required by the Clean Water Act.

   —For water physiochemistry, we use aquatic-life chronic criteria with the goal of providing advance warning of an impending problem before it becomes severe.

2. **Compare SEI data to existing and relevant ecological thresholds.** In some cases the true nature of the threshold may not be fully understood and therefore our interpretations of these boundaries are cautious. We apply this to a few key water or sediment chemistry constituents, and several biological and habitat metrics.

3. **Compare SEI data to novel ecoregion assessment point values** derived from distributions of reference site data from the surrounding Middle Rockies ecoregion. We apply this to a few key water chemistry constituents, and several biological and habitat metrics.

   —For setting assessment points in distributions from ecoregion reference sites we follow EPA guidance for the percentile values used to establish non-reference/reference assessment points.

4. **Compare SEI data baselines** derived from partner or auxiliary data. derived from USGS gauge data or other auxiliary data. Once we have accrued sufficient SEI data we may use our own data to generate baseline assessment points as well.

Quality Assurance and Quality Control

Two of the more important requirements of long-term monitoring program are to assure (1) that data are of high quality, and (2) that response measures and metrics are valid estimators of the endpoints of interest that facilitate meeting monitoring objectives. The ROMN SEI protocol (Schweiger et al. In Review) and associated SOPs including the ROMN Quality Assurance Performance Plan specify various field and laboratory quality assurance and quality control (QAQC) procedures (summarized in Appendix E) that address the first of these.

The implementation of the SEI protocol at LIBI presents some challenges for meeting the second QAQC requirement. Ideally, we would have a large sample size of independent sites on the Littler Bighorn in LIBI with these well replicated data allowing estimation of sources of variation in stream condition to statistically determine the quality of SEI indicators. The ROMN is implementing this strategy in our large parks (currently, Glacier NP for streams and Rocky Mountain NP for wetlands), but in LIBI we are not able to sample multiple independent sites due to the restricted extent of the stream resource in the park and ROMN budget constraints. A similar approach might be used with replicates at a single or few sites, although this presents some issues with pseudoreplication and temporal autocorrelation.

Signal to Noise Ratio

One way we are overcoming the issue of limited independent replicates is to borrow relevant results from similar monitoring. We use a relatively simple statistic generated for EMAP data (see above; Stoddard et al. 2005, P. Kaufmann, US EPA, Pers. Comm, summer, 2012) called "signal to noise" (S:N). S:N is the ratio of variance between multiple sites (signal) and the variance of repeated visits to the same site (noise). Loosely speaking, it is a measure of the repeatability of a measure. A low S:N value indicates that a metric has nearly as much variability within a site (over time) as it does across different sites, and thus indicates a measure that does not distinguish well between sites. A high S:N value suggests a response that has lots of signal or real information. S:N is derived using a general linear model to compare the within-year variance among streams (signal) with the variance between repeat visits within the same year (noise). The noise variance includes the combined effects of within-season habitat variation, differences in estimates obtained by separate field crews, and uncertainty in the precise relocation of plots.

We report S:N values from data sampled during 2000-2004 by EMAP at 1,524 sites across the western U.S. We do this for select SEI biological and habitat responses collected at LIBI where we use the same methods as EMAP. Because this approach assumes that SEI crews perform identical to EMAP crews and that there is no systemic difference in the years used (2000-2004 vs. 2008-2010), we only use the EMAP S:N as rough guides. Note that there are EMAP sites in this data set near LIBI (see Figure 7).

Results and Discussion

Sample Sites and Events

From 2007 to 2010 a total of eight sample events were conducted at the LIBI SEI sentinel site (Table 4). These include "sentinel" samples where only water and sediment were collected and "full" or "base" sample events with a complete implementation of the SEI protocol. There were no sample events in 2008 due to ROMN budget constraints.

Water and Sediment Physiochemistry

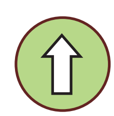
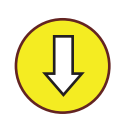
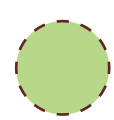
Summary

In general, water and sediment physiochemistry was in reference state in 2007-2010, with few exceedances of State of MT criteria or meaningfully elevated concentrations for parameters without established criteria. Table 5 presents a simple summary of these results with more details below.

Table 4. SEI sample events at LIBI, 2007-2010.

Event Date	Event Description	Hydrograph Limb	Notes
10/04/2007	Targeted collection of benthos and periphyton, water physiochemistry	Base	Non-standard SEI site layout for biology; no sediment or habitat measures
05/17/2009	Water and sediment physiochemistry	Rising	Sentinel sample event
08/10/2009	Water and sediment physiochemistry, benthos, periphyton, all habitat responses, instantaneous discharge	Base	Full sample event across complete sample reach; co-sampled with USGS and EPA as a reference site for the National Rivers and Stream Assessment
11/15/2009	Water and sediment physiochemistry	Base/Winter	Sentinel sample event
5/10/2010	Water and sediment physiochemistry	Rising	Sentinel sample event
6/16/2010	Water and sediment physiochemistry	Peak	Sentinel sample event
8/18/2010	Water and sediment physiochemistry	Base	Sentinel sample event
10/27/2010	Water and sediment physiochemistry	Base/Winter	Sentinel sample event

Table 5. Summary condition table excerpt for select water and sediment measures at LIBI from 2007 to 2010. We include example vital signs and indicators, a brief description of results and patterns, and symbolize the status, trend, and our confidence in those summaries. See the Executive Summary for the complete Summary Condition Table.

Vital Sign (Example Indicators)	Summary	Symbol
Water physiochemistry (major ions, nutrients, metals)	Nutrients, major ions, and metals concentrations were all acceptable with few exceedances of State of Montana water quality criteria for aquatic life (or human health). Maximum (but not median) sulfate concentrations were higher than at ecoregion reference sites. While patterns are mixed, the long-term trend in several water physiochemistry parameters may be improving. We have medium confidence in our assessment of major ions, nutrients, metals at LIBI.	
Water in-situ chemistry (pH, conductivity, DO, temperature)	All of the core NPS parameters were in an acceptable reference range. Dissolved oxygen needs more careful monitoring. The long-term trend in stream temperature suggests rising water temperature - or a deteriorating condition (but the period of record is short). We have medium confidence in our assessment of in situ parameters at LIBI.	
Sediment chemistry (metals)	Most metals were present in low concentrations and did not exceed informal consensus-based sediment criteria. We suspect the source of most metals is natural. We lack data to assess trends in metal concentrations. We have lower confidence in our assessment of sediment chemistry at LIBI given the lack of clearly relevant criteria.	

Of particular note, dissolved oxygen did have an instantaneous minimum below warm water criteria, but we saw no evidence of any ecological consequences from this and more detailed data are required to properly assess this issue. The results from the trend models indicate that there are complex patterns in water quality over the last two or three decades at the Hardin USGS gauge (and likely LIBI). In particular, an increasing trend in stream water temperature may have real biological consequences. However, a decrease in conductivity reflects real a meaningful (and improving) trend in water physiochemistry.

Measures, Criteria, and Assessment Points

Table 6 presents a summary of the status of SEI water physiochemistry results for 2007-2010. We interpret results following the general ROMN assessment approach as outlined above. All interpretations are done in the context of the ecology of the Little Bighorn River and management needs for LIBI (i.e., maintaining the historic context of the Little Bighorn battle).

Many constituents have formal State of Montana water quality criteria (as well as assessment points from other sources used by the State). As noted above, when using MT DEQ criteria NPS cannot formally interpret data in the context of meeting designated uses. Given the large number of existing MT state water quality criteria we only compare two parameters, sulfate and chloride, to assessment points derived from the surrounding ecoregion. Both of these constituents are known to be useful indicators of general anthropogenic disturbance (Stoddard et al. 2005), and we feel that qualitative comparisons to ecoregional assessment points provide useful context for interpretation at LIBI.

Table 6. Summary of water and sediment physiochemistry for the Little Bighorn River in Little Bighorn National Battlefield, 2007-2010. Except as indicated, assessment points are state of MT chronic aquatic-life criteria with human-health values in parentheses. All assessment points define non-reference except those in green[4]. The non-reference state is above all assessment points except for those with an inequality indicating that it is below the value. Concentrations in **bold red** indicate results in non-reference at least once during 2007-2010. Values in **bold** are either intermediate or non-reference (depending on the existence of a non-reference assessment point). For additional clarifications on Table content see Notes below.

Constituent or Property	No. Analyses[0]	Minimum Value	Median Value	Maximum Value	Criteria or Assessment Points
Field properties					
Temperature, water (°C)	6[x]	5.8	17.21	21.97	--
Oxygen, dissolved (mg/L)	6[x]	**4.42**	9.22	12.28	<5, <3[1]
pH (standard units)	6[x]	8.05	8.55	8.9	(see below)[2]
Specific conductance (µS/cm)	6[x]	378.17	527.19	767.39	1500,100[3]
Major constituents, dissolved					
Alkalinity, dissolved (mg/L as $CaCO_3$)	8	189.36	205	239.19	--
Calcium, dissolved (mg/L)	7	54.83	63.97	76.91	--
Chloride, dissolved (mg/L)	8	**1.37**	**2.14**	**3**	4.4, 10.4[4]
Fluoride, dissolved (mg/L)	3(2)	0.27**	0.27**	0.27**	(4)
Hardness, dissolved (mg/L as $CaCO_3$)	7	173	272	327	--
Magnesium, dissolved (mg/L)	8	71.62	27.8	37	--
Potassium, dissolved (mg/L)	7	0.98	1.77	2.68	--
Silica, dissolved (mg/L as Si)	8	4.23	5.91	7.54	--
Sodium, dissolved (mg/L)	7	11.39	24.05	56.55	--
Sulfate, dissolved (mg/L as SO_4)	8	**45.51**	**98.79**	**227.66**	112.9, 722.8[4]
Total Suspended Solids (mg/l)	4	6	26.06	63.8	--

Table 6. *Summary of water and sediment physiochemistry for the Little Bighorn River in Little Bighorn Battlefield National Monument, 2007-2010 (continued).*

Constituent or Property	No. Analyses[0]	Minimum Value	Median Value	Maximum Value	Criteria or Assessment Points
Nutrients in water or periphyton, dissolved and/or total recoverable					
Ammonia, dissolved (mg/L as N)	8(6)	0.004*	0.006*	0.02	0.9[5]
Nitrite + Nitrate, dissolved (mg/L as N)	8(4)	0.0005*	0.002*	0.07	0.076(10)[6]
Nitrite, dissolved (mg/L as N)	7(4)	0.0005*	0.001*	0.005	(1)
Nitrate, dissolved (mg/L as N)	7(1)	0.0003*	0.003	0.06	(10)
Nitrogen, total (mg/L as N)	8	0.08	0.14	0.26	1[7]
Orthophosphate, dissolved (mg/L as P)	8(4)	0.0006*	0.001*	0.004	--
Phosphorous, total (mg/L as P)	8	0.002	0.005	0.01	0.12[7]
Carbon, organic, dissolved (mg/L as C)	8	2.61	2.9	12.76	--
Carbon, organic, total (mg/L as C)	4	1.5	2.5	2.6	--
Chlorophyll-a in periphyton (mg/m^2)	2	0.03	10.08	20.14	120[8]
Ash Free Dry Mass in periphyton (g/m^2)	2	6.2	17.3	28.4	35[8]
Metals in water, total recoverable					
Aluminum, total (µg/L)	7(2)	74.2*	1020*	2920	--
Arsenic, total (µg/L)	8(8)	--	--	--	150(10)
Barium, total (µg/L)	4	50	57	73	(1000)
Beryllium, total (ug/L)^	4(4)	--	--	--	(4)
Cadmium, total (µg/L)	3(3)	--	--	--	0.5(5)[9]
Chromium, total (µg/L)^	4(4)	--	--	--	(100)
Copper, total (µg/L)	8(8)	--	--	--	20(1300)[9]
Iron, total (µg/L)	8(1)	20.37*	**601***	**4860**	1000(300)[9,10]
Lead, total (µg/L)	8(8)	--	--	--	9.7(15)[9]
Manganese, total (µg/L)	8(2)	1.36*	23.75*	**197**	50[10]
Selenium, total (µg/L)^	8(8)	--	--	--	5(50)
Zinc, total (µg/L)^	4(4)	--	--	--	252(2000)[9]
Metals in water, dissolved					
Aluminum, dissolved (µg/L)^	8(7)	--	--	--	87
Arsenic, dissolved (µg/L)	7(7)	--	--	--	150(10)[11]
Barium, dissolved (µg/L)	3	47.2	54.8	73.6	--
Beryllium, dissolved ug/L)^	4(4)	--	--	--	--
Cadmium, dissolved (µg/L)^	3(3)	--	--	--	0.44(4.33)[11]
Chromium, dissolved (µg/L)^	3(3)	--	--	--	(86)[11]
Copper, dissolved (µg/L)	7(7)	--	--	--	3.6(1248)[11]
Iron, dissolved (µg/L)^	7(7)	--	--	--	--
Lead, dissolved (µg/L)	7(7)	--	--	--	0.35(9.7)[11]
Manganese, dissolved (µg/L)	7(4)	0.13*	0.72*	6.73	--
Selenium, dissolved (µg/L)^	7(7)	--	--	--	5(50)[11]
Zinc, dissolved (µg/L)^	4(4)	--	--	--	36.5(1972)[11]
Metals in sediment					
Aluminum, total (mg/kg)	7	3700	4500	7350	--
Arsenic, total (mg/kg)	7	**3.9**	**4.4**	**6.1**	9.79,33[12]
Barium, total (mg/kg)	7	109	138	159	--
Beryllium, total (mg/kg)	7	0.3	0.4	0.5	--
Cadmium, total (mg/kg)	4(4)	--	--	--	0.99,4.98[12]
Chromium, total (mg/kg)	7	6.3	7.2	10.7	--
Copper, total (mg/kg)	7	**5**	**7.2**	**13.2**	31.6,149[12]

Table 6. *Summary of water and sediment physiochemistry for the Little Bighorn River in Little Bighorn Battlefield National Monument, 2007-2010 (continued).*

Constituent or Property	No. Analyses[0]	Minimum Value	Median Value	Maximum Value	Criteria or Assessment Points
Metals in sediment (continued)					
Lead, total (mg/kg)	7	**5.7**	**6.7**	**12.7**	35.8,128[12]
Iron, total (mg/kg)	7	8910	9690	13900	--
Mercury, total (mg/kg)	7(7)	--	--	--	0.180,1.06[12]
Selenium, total (mg/kg)^	7(7)	--	--	--	--
Silver, total (mg/kg)	7(6)	0.9*	0.9*	0.9	--
Zinc, total (µg/L)	7	**24**	**28.8**	**51**	121,459[13]

Notes

All water quality assessment points are State of Montana chronic aquatic life criteria (MT DEQ, 2010) with human health standards in parentheses except as follows:

[1] Freshwater Aquatic Life Standards for DO are warm water 1 day minima for (1) early life stages followed and (2) other life stages. They are instantaneous water column concentrations to be achieved at all times (MT DEQ 2002).

[2] Induced variation of hydrogen ion concentration (pH) within the range of 6.5 to 9.0 must be less than 0.5 pH unit. Natural pH outside this range must be maintained without change. Natural pH above 7.0 must be maintained above 7.0 (MT DEQ 2002).

[3] Conductivity assessment point (EPA 2007a) is a growing season instantaneous maximum followed by a monthly average as developed for the Tongue River mainstem and is applied informally and with caution to LIBI.

[4] Assessment points for sulfate and chloride are generated from reference sites in the Northwestern Great Plains ecoregion at the <50th or >75th percentile values for reference/ non-reference, respectively (Stoddard et al. 2005, 2006).

[5] MT DEQ (2010) ammonia criteria is a table value lookup for a chronic value for total recoverable ammonia nitrogen at a pH of 8.4 at 20° and assuming early fish life stages are present.

[6] Nitrite + Nitrate is provisional and for a base flow in the Northwestern Great Plains Ecoregion (Suplee et al. 2008), the human health standard is from MT DEQ (2012e).

[7] Total P and N are proposed for base flow in the Northwestern Great Plains Ecoregion (Suplee and Sada de Suplee 2011, Suplee et al. 2008).

[8] Nutrient assessment support criteria from MT DEQ (2011a) derived for the Northwestern Great Plains Ecoregion and are used with caution as MT DEQ uses nutrient, DO and periphyton assemblages in eastern Montana for formal assessment; Note the different units (mg/m^2 vs. g/m^2).

[9] Table values calculated at a median hardness of 272 mg/L as $CaCO_3$.

[10] Human health value is a secondary standard based on aesthetic properties such as taste, odor, and staining and is more conservative than chronic standards. MT DEQ does not assess iron secondary standards that apply to taste and odor to water.

[11] Values for dissolved trace elements are derived from the State of Montana water quality numeric standards total values using formulas from US EPA (2009) and a median hardness of 272 mg/L as $CaCO_3$.

[12] Sediment criteria are consensus based Threshold of Effect Concentrations (TECs) followed by Probable Effect Concentrations (PEC) values from MacDonald et al. (2000). TECs are concentrations below which no effect on sediment dwelling organisms are expected, where as PECs are the concentrations at which negative effects on sediment dwelling organisms are judged more likely to occur than not.

Non-detect Notes

[0] Values for sample size are total N with the number used in ROS models for non-detects in parentheses.

* Value or median contains predicted results from ROS model.

** >80% of results at Detection Limit(s), results tenuous.

^ All results at Detection Limit(s), no model possible.

Other Notes

[x] N for field properties is the number of events (the number of discrete data values within each event ranges from 1 to ~100).

--, not detected; No., number; mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorous.

Quality Assurance and Quality Control

Signal to noise values are not readily available from EMAP for water chemistry data. Therefore QAQC for SEI water physiochemistry is currently restricted to field and lab procedures as discussed in Appendix E. In summary, data are not included in the results presented here unless they passed all field and lab QAQC procedures. When we have enough replicates, additional QAQC will be included in future reports. Appendix E presents mode details on ROMN QAQC procedures. Appendix G presents laboratory detection limits for water chemistry parameters.

In Situ Parameters

In situ water chemistry during SEI sentinel events showed a fairly high degree of variation. There were few exceedances of the available assessment points for *in situ* parameters and none that met all of the requirements for applying State of Montana water quality criteria.

Instantaneous water temperature ranged from around 5° to over 21°C. Qualitatively speaking, this range is not excessively hot or cold for a low-gradient river like the Little Bighorn in LIBI. State of Montana classification standards for a class B-2 river like the Little Bighorn are focused on point-source discharges and are not easily applied to SEI data (MT DEQ 2002). Unlike in other ROMN parks, there are no fish species at LIBI that provide potentially relevant temperature criteria. Continuous data collected using SEI temperature loggers and harvested from the USGS gauge near Hardin are better assays of temperature dynamics at LIBI.

Specific conductance (SC) ranged from 378 to 767 μS/cm with a median around 527 μS/cm. Specific conductance was marginally inversely related with discharge (as measured at the Hardin gauge; $r=-0.59$, $p=0.09$, $N=12$), with maximum conductance during low-flow conditions. Similar models for data from the nearby Tongue River watershed (EPA 2007a) suggest that the relationship between flow and SC varies depending on the magnitude of the flow with a positive relationship at low flow and a negative relationship at high flows. This may be due to groundwater forming a larger component of streamflow during low-flow conditions. Ground water often has higher concentrations of dissolved solids (and hence higher conductance) than surface water due to longer rock-water interaction time. The State of Montana (ARM 17.30.670) has maximum and average numeric criteria for salinity (as measured by SC in μS/cm) for the mainstems of Rosebud Creek, the Tongue, Powder, and Little Powder rivers. These assessment points are used directly to measure agricultural beneficial use impairment. These watersheds are adjacent to the Little Bighorn. While they have a greater degree of development (from coal bed methane and other extractive land uses) their geology and general landforms are similar. We apply these criteria to the LIBI data in an informal and qualitative way given their specificity and the data requirements. While instantaneous maximum SC at LBI was fairly high, it did not exceed the highest criterion value for these adjacent and more disturbed watersheds. A modeling analysis conducted in the Tongue River to estimate salinity levels that may have occurred in the absence of human influence suggested that mean SC under the simulated natural condition is not significantly different than the simulated existing (anthropogenically modified) condition (EPA 2007a) suggesting that the source for elevated levels in this nearby watershed are likely natural.

The State of Montana has established a minimum instantaneous dissolved-oxygen concentration of 5 mg/L for early life stages of fish and 3 mg/L for other life stages in warm water rivers like the Little Bighorn (MT DEQ 2002). These are instantaneous water column concentrations to be achieved at all times, although the ideal or most relevant point in the diel cycle to measure DO is at dawn. Dissolved oxygen at LIBI was above the criterion (or in a reference condition) other than a late summer reading in 2010 which was below the 1 day minima for early life stages of warm water fish.
It is unlikely that this was a biologically important exceedance that resulted in any fish kills at LIBI (we know of none). In general, DO concentrations were greater

during winter and spring and decreased in late summer (although our sample size by season is very small) when water temperatures and biological respiration in the river is increased. As our sample size of DO in the Little Bighorn increases these data will be more and more useful for comparison to proposed State of Montana criteria.

Finally, the State of Montana (ARM 17.30.626) established classification standards for B-2 waters that state any induced variation of pH within the range of 6.5 to 9.0 must be less than 0.5 pH units, that natural pH outside this range must be maintained without change and natural pH above 7.0 must be maintained above 7.0 (MT DEQ 2002). There is no manipulation of pH by the NPS within LIBI and while there are complex interactions with other water physiochemistry parameters that can influence pH, some of which do have anthropogenic sources upstream and within LIBI, there is no evidence that pH within the Little Bighorn in 2007-2010 was not "natural." Our episodic measurements of in situ pH in the Little Bighorn were all above 7.0. Most were actually somewhat basic probably due to source material in the surficial geology of the watershed.

In general, *in situ* results from LIBI do not suggest any problems in water quality. However, these parameters can vary strongly over the course of 24 hours (i.e., by temperature or from sorption of metals between water, sediments, aquatic plants (Nimick 2003). Diel fluctuation, beyond that measured over the 2 to 4 hours of most continuous data collected during SEI sample events, is not included in the values in Table 6 and so our field parameter results should be treated with caution.

Major Constituents

Major dissolved constituents at LIBI were dominated by calcium, bicarbonate, and sulfate. Alkalinity ranged from 189 to 239 mg/L, indicating that the Little Bighorn in LIBI was well buffered. There are few existing state or federal criteria for anions and cations and the one defined by the State of Montana (a human health standard for fluoride) was not exceeded by SEI data. As of the time of this reports publication MT DEQ and EPA were developing guidance for a chloride criterion (Darrin Kron, Pers. Comm., 2013). When these are available we will informally apply them to SEI data. However, because chloride (and sulfate) are important indicators of possible general anthropogenic disturbance (i.e., Biggs et al. 2004) we developed ecoregional assessment points to aid in the interpretation of the measured concentration of these chemicals at LIBI. Based on surrounding ecoregion reference sites, a reference concentration was below 4.4 and 112.9 mg/l for chloride and sulfate, respectively. The non-reference state above 10.4 and 722.8 mg/l, for chloride and sulfate, respectively.

The median concentration of sulfate (98.79 mg/L) from 2007 to 2010 was between the non-reference and reference assessment points (or in an intermediate state). Maximum sulfate levels (227.6 mg/L) did exceed the ecoregion non-reference assessment point value although the minimum and median values were intermediate. All chloride concentrations from 2008-2010 were in a reference state when compared to ecoregion reference site levels. This suggests LIBI may have had maximum concentrations of sulfate above the ideal as measured at reference sites across the ecoregion. Anthropogenic sources of chloride and sulfate include fertilizers, a suite of industrial chemicals, sewage, irrigation drainage, combustion of fossil fuels, mining activities, and paper or textile production—some of which occur in the watershed above LIBI.

However, SEI monitoring cannot conclusively link concentrations of these two anions to any of these sources. Sulfate can be derived from weathering of carbonate minerals and gypsum in the marine sedimentary rocks that are common in the area (Vuke et al. 2000). Sulfate is often the dominant anion in southeast Montana streams (USGS 2001, 2002) and can vary greatly depending upon flow. Chloride is also widely distributed in nature (it constitutes about 0.05% of the earth's outer crust), generally in the form of sodium and potassium salts. Bright and Addison

(2002) show that natural background concentrations of chloride are on the order of 1 to 100 mg/L. Moreover, concentrations of these two chemical were very low at reference sites in the ecoregion (i.e., older EPA criteria (EPA 1988) suggest reference chloride concentrations for streams and rivers based on chronic toxicity to plant, fish, and invertebrate species are below 230 mg/L, not the very low 4.41 mg/l value seen in ecoregion reference sites) and we are hesitant to conclude that there were problems at LIBI stemming from chloride or sulfate during 2007-2010.

Using data from the late 1990s, Mast (2007) suggested that concentrations of most major constituents were lowest during high flow when there were large contributions of dilute snowmelt to the river. We see similar patterns across season in the 2007-2010 SEI data, although both studies had small sample sizes. As we accrue more SEI data we will investigate seasonal impacts on trends and instantaneous concentrations of ions in the river.

Total suspended sediment (TSS) concentrations increased from around 4 mg/L during low-flow conditions to over 63 mg/L during high-flow conditions, reflecting greater kinetic energy for erosion and transport. While these are relatively low concentrations of suspended sediment, we saw suggestions (significant, but based on very small sample sizes) of positive correlations between TSS and several metals and major ions. Currently, a likely limiting factor on loading of suspended sediment to streams is the rate of supply of material to the stream channel from natural or anthropogenic disturbance.

Nutrients

Nutrients collected at SEI LIBI events included several forms of nitrogen (ammonium, nitrite + nitrate, total nitrogen, etc.), phosphorous (total and orthophosphate), and organic carbon. The State of Montana has developed a rigorous assessment methodology for determining wadeable stream impairment due to excess N and P. Suplee and Sada de Suplee (2011), or supporting research conducted by MT DEQ and cited within, details field, laboratory, QAQC, and analytical approaches for determining if a stream reach has a nutrient problem. The methods include a tiered or decision pathway based approach and allows (or requires) supporting data from productivity and biological metrics (in addition to N or P concentrations). Proposed nutrient criteria are also specified (MT DEQ 2011a) that differ from EPA or previous state criteria in several useful ways. For example, they are specific to summer months (July to September) when stream ecosystems are often most stressed due to low-flow conditions and elevated temperature, they vary by ecoregion or even by stream, and they were derived from a modeling exercise comparing nutrient data to biological response and human-perception of eutrophication.

We are fortunate to have the MT DEQ nutrient protocol available to apply within SEI monitoring at LIBI. The SEI protocol provides many of the data elements required to implement the MT DEQ methodology. However, some specific data collection and analytical requirements are not currently supported by SEI methods. For example, a 12-sample minimum during a base flow time period is needed as there is an allowed exceedance rate of 20% with a specific statistical test required to ascertain significance of a possible impairment. Therefore, at this time we cannot fully or appropriately apply the MT DEQ approach to assessing nutrients and our current efforts should be considered to only be laying the groundwork for possible future application of the complete method.

In general, nutrient concentrations at LIBI were low and near or below detection limits (note that the laboratory used by the ROMN for nutrients has very low detection limits). Nitrite + Nitrate approached the proposed criteria once but no SEI nutrient data meet the suite of requirements that would allow MT DEQ to conclude that there was a nutrient impairment on the Little Bighorn at LIBI during our sample events in 2007 to 2010.

As with many ions there are likely seasonal patterns in nutrient concentrations at LIBI. We saw higher nitrogen concentrations during spring flows and during late fall or winter sample events. Runoff from agricultural fields or pastures upstream from the park may drive elevated spring levels and higher nutrient concentrations in winter may be due to greater contributions of nutrient-enriched groundwater to streamflow coupled with decreased biological demand during colder winter months, although both of these causes are only speculative. Land use data from upstream land owners might help resolve these questions.

Chlorophyll-a and AFDM from periphyton can be used by MT DEQ as related or supporting information in nutrient assessment but are not diagnostic by themselves (MT DEQ 2011a, Suplee and Sada de Suplee 2011). We therefore apply these proposed criteria in isolation to LIBI SEI data with caution. Chlorophyll-a at LIBI did not exceed the proposed state criteria. AFDM was relatively high in 2007 but still below the proposed criteria.

Dissolved carbon (DOC) is not part of the MT DEQ nutrient methodology; however, it is a useful constituent to include in long term monitoring (Hauer et al. 2007). In Montana larger rivers or streams associated with wetlands DOC values may approach 50 mg/L of C (Hauer and Lamberti 2006). DOC values at LIBI were below this value.

Metals in Water

We focus on total metals given State of Montana criteria for total, rather than dissolved concentrations (except aluminum, which has a dissolved fraction criteria from the State). Total metals represent all metal in a sample, whether they are bound to sediment, are in particulate form or are dissolved. A dissolved metal fraction is the fraction that is in solution only. Note that data on metals only found bound to sediments are presented below. While most State of Montana criteria are for total metals, because it is primarily the dissolved form that causes aquatic toxicity the EPA has recommended that criteria for metals be re-expressed as dissolved concentrations (EPA 1996). Therefore, we also include and present dissolved metals including, where available, criteria following methods in EPA (2009a). Note that many of the aquatic-life water quality standards for metals vary according to the hardness of the water and we use adjusted values as needed.

Metals rarely occurred in detectable amounts in SEI samples at LIBI during 2007-2010. Low concentrations may reflect a lack of urban and mining areas upstream or a more basic pH that can reduce the measurable metals in the water column. However, total aluminum, dissolved and total barium, total iron, and dissolved and total manganese were detected in a few samples. The maximum total iron and manganese values were above there aquatic-life standards and the median iron concentration above its human health standard. However, we suspect that this reflects the natural geology in the watershed but will require more data to resolve. Similar patterns have been seen on the Tongue River with total iron, but the EPA (2007b) states that a detailed source assessment is required to isolate any anthropogenic localized cause of the high iron concentrations.

Metals in Sediment

There are no published State of Montana numeric standards for metals in sediments. However, MacDonald et al. (2000) developed Threshold Effect Concentrations (TEC) and Probable Effect Concentrations (PEC) for select metals in the Clark Fork and we informally and cautiously apply these to LIBI data. TECs and PECs are consensus values derived from multiple studies of the effects of metals in sediments and are expressed as a geometric mean of the individual thresholds these studies indicated were potentially thresholds in the impacts of concentrations of a given metal in sediment.They have been tested for their reliability in predicting toxicity in sediments by using matching sediment chemistry and toxicity data. TECs are a lower (or reference) threshold, below which there are likely no impacts and PECs are an upper (or non-reference) threshold, above which impacts are likely.

Although there were detectable amounts of nearly all measured metals in SEI samples from the sediments of the Little Bighorn, they were all below TEC concentrations (or in reference) and well below the non-reference PEC assessment point. Patterns among sediment metal concentrations, discharge, and seasons were difficult to resolve given small sample sizes, and will have to be addressed with more data in the future. Of special note, total mercury was not detected in any LIBI sample. However, because the primary toxic form of mercury is methylmercury, total mercury-based toxicity estimates are not expected to be highly accurate. MacDonald et al. (2000) note that TEC assessment points correctly predicted total mercury toxicity only 34% of the time, whereas the consensus-based PEC correctly predicted toxicity 100% of the time. While the success of using total mercury and the TEC value is somewhat low, the consequences of actual mercury toxicity are severe enough that we feel it is still a useful assessment point.

Several factors suggest caution when interpreting LIBI SEI metals in sediment data. Most importantly, we have a very small sample size, and our samples are episodic and not connected to events like storms that might mobilize metals. We have a small sample size and our samples are episodic and not connected to events like storms that can mobilize metals in sediments. SEI sediment samples are composited across multiple depositional areas along the sample reach (where fine grained sediments collect) which should reduce small scale spatial variability. However, we cannot collect samples from riffles where MacDonald et al. (2000) show concentrations are often 30 to 40 percent lower than in depositional areas. Riffles are often key habitat for benthos that support fish populations.

Special Case: Water Temperature

In the following section we present additional analyses of continuous water temperature data from SEI loggers, a NPS gauge maintained in LIBI for water years 1999 to 2006 (these data was provisional as of the time of publication) and a USGS gauge near Hardin, MT that has been active since the early 1920s. Our focus is on developing baselines from these contemporary water temperature data for comparison into the future. We also use these data to conduct a seasonally adjusted model of trend in water temperatures (presented in the trend results section below).

Baselines

We develop a baselines for future comparisons of stream temperatures using mean August temperature (again from daily values at the gauge; Table 7) suggests a possible baseline of around 22ºC (the average across all water years). We use August temperatures because this is generally (July may also be) the hottest month of the year and may be when warming trends are most evident as climate regimes shifts over time. August is also generally when base flow is first reached during the water year and when stress from reduced flows (and elevated water temperatures) may occur. However, the choice of a specific temperature statistic to use as a baseline is complex and we are also exploring alternatives (Dettinger et al. 2004, Isaak et al. 2011, Arismendi et al. 2012).

Table 7. Mean August stream water temperature from daily means at the LIBI NPS WRD gauge (2001-2007) and the SEI logger (2010 and 2011). Sample size for 2001-2007 was 31 with 22 and 29 in 2009 and 2011 (respectively).

Water Year	Mean August Temperature (ºC)	Standard Deviation
2002	17.2	1.48
2003	25.2	0.66
2004	21.4	1.74
2005	21.8	2.29
2006	23.0	1.51
2007	22.7	1.62
2010	21.4	1.29
2011	23.1	0.71

We will continue to assess the usefulness of this baseline, including comparisons to other approaches or baseline statistics, and use them in future reports as warranted. However, several complex factors control stream temperatures (i.e., latitude, elevation, groundwater, turbulence, direct solar radiation, ambient temperatures, aspect, etc.) and these should also be considered in evaluating the relevance of these baselines and in interpreting any observed changes in stream temperatures relative to these values. The trend models presented below accomplish this to a degree by statistically accounting for discharge and season. If we use the value given above we will need to think at least about stream discharge and potentially ambient air temperature in our interpretations. The discharge-temperature relationship has important implications under a shifting climate regime where stream flow is expected to be strongly affected (Arismendi et al. 2012). From 2001-2007, spring through summer discharge and daily mean temperature were negatively correlated ($r = -0.33$, $p < 0.05$). Low discharge tends be correlated with both slower water velocity and shallower areas in the channel which can create warmer stream water temperatures. As we present below, at least the more recent years (2007 to 2010) in this time period were typical years with generally average discharge compared to the 30 year normal. This may suggest that this baseline is relatively stable or at least not strongly influenced by stream flow relative to the historic norm. Arismendi et al. (2012) demonstrated trends toward a shorter time lag between maximum stream temperature and minima in discharge at over 20 undammed sites (like the Little Bighorn) across the west with a strong negative association between their magnitudes. Aquatic biota in these systems may be increasingly experiencing narrower time windows to recover or adapt between extreme events of low flow and high temperature.

Recent Water Temperatures

Figure 8 presents LIBI SEI daily temperatures from 2009 to 2010 collected by the SEI logger. Figure 9 presents similar time series plots of daily mean water temperature at the NPS WRD gauge by water year from 2001-2007. Note we include stream discharge (from the USGS Hardin gauge as NPS discharge data were not available) on these figures. Temperatures in the Little Bighorn followed an expected seasonal pattern with cold winters and sometimes hot summer periods.

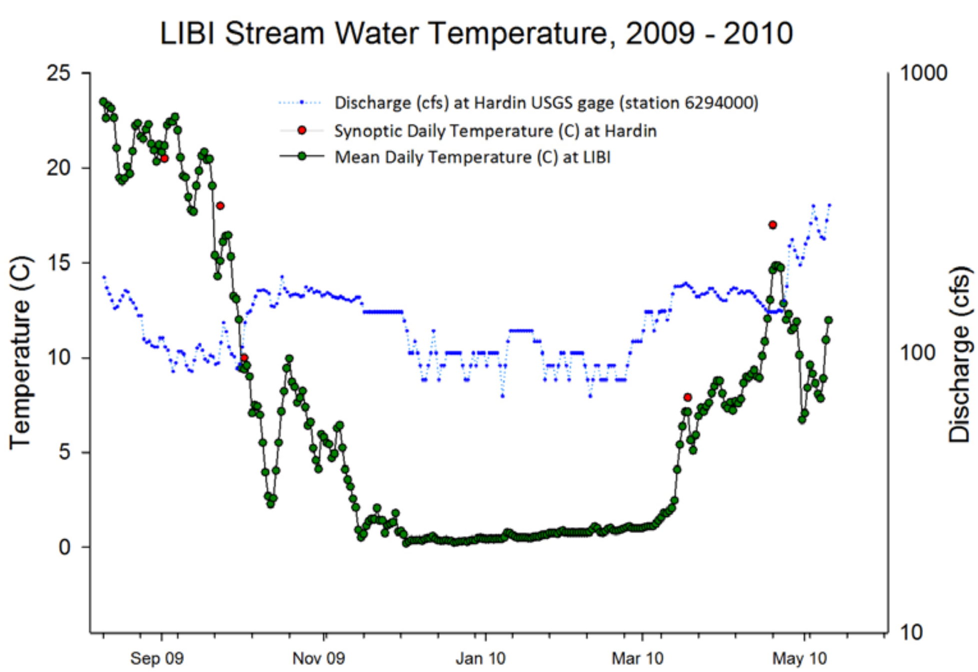


Figure 8. Mean daily stream temperature in 2009-2010 (green dots) for the SEI logger at the LIBI site. Red dots indicate instantaneous temperature at the USGS station in Hardin. Discharge in cubic feet per second (light blue line) at the USGS station near Hardin is shown for context. Note that given the available data the time interval shown (not a true water year) on this figure differs those on Figure 9.

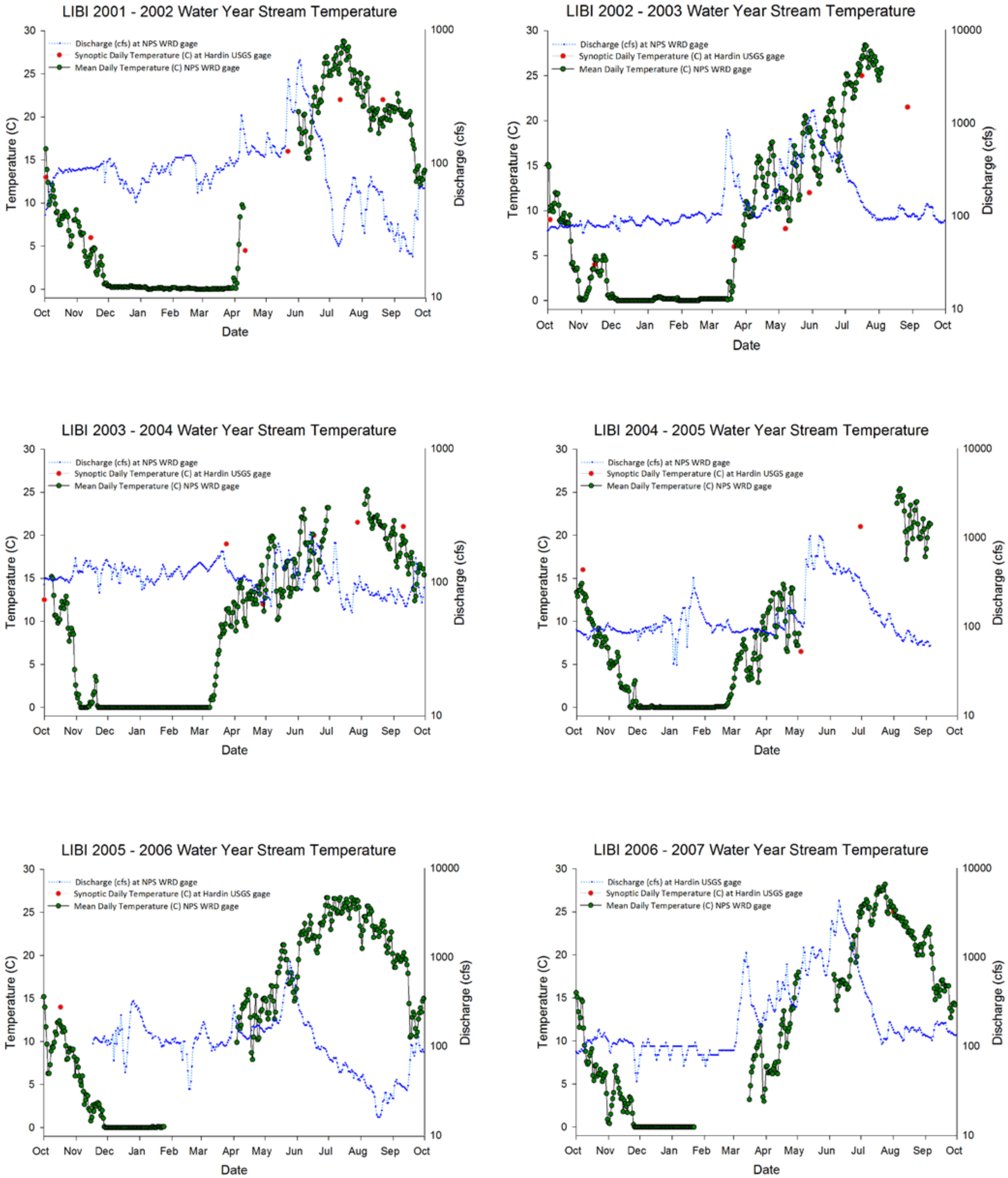


Figure 9. Stream temperature (green dots) at the NPS WRD gauge in LIBI by water year from 2001-2002 to 2006-2007. Discharge (light blue line) from the USGS gauge at Hardin is shown for context. Synoptic temperature data from the USGS gauge in Hardin are shown with red points

Freeze-thaw phenology

Although our sample size is small, seven years of data from the NPS gauge suggest that the phenology of freeze-thaw cycles on the Little Bighorn may be shifting. Table 8 gives the first and last days of freeze from 2001-2009. Only five water years from 2001-2005 and 2009-2010 had sufficient data for estimating both freeze and thaw. Dates of thaw were consistently earlier in each successive year but there was no consistent pattern in dates of freeze. However, this is a very small sample and we can't over interpret this pattern as necessarily similar to what has been shown for a larger data set and longer time period in the western U.S. (Pederson et al. 2010, Isaak et al. 2011). Future work with more data will allow more complex analyses of the phenology of freeze-thaw on the Little Bighorn. *Importantly, more data and rigorous modeling are needed to confirm these patterns in stream temperature phenology*.

Select Trends in Water Physiochemistry

SEI data in LIBI proper are not yet of sufficient duration to estimate any true trend models. Therefore, we used data from the USGS station in Hardin to test for longer-term trends in select physiochemistry measures. We must assume that these data are relevant to LIBI which may be somewhat tenuous given the distance and the fairly intense land use between the gauge and LIBI. There are no overlapping sample dates for the chemistry data at the gauge (which stopped in 2001) and SEI data collection, so we cannot make any meaningful comparison to see if data at the two locations were comparable. Given this, we do not interpret any absolute values in concentrations in the USGs data and omit any comparison of trends to criteria.

The ESTREND tool we use (Schertz et al. 1991, Slack and Lorenz 2003) is a regression model that computes an annual trend (slope), which represents the median rate of change in concentration or discharge for the selected period of record. Following USGS convention, trends were considered statistically significant at the 0.1 probability level. The model uses nonparametric seasonal Kendall tests or a parametric Tobit model to account for variation across time due to season. The specific number of "seasons" or form of the flow model adjustment for a parameter is determined by pattern in and the density of data. ESTREND may also use daily mean discharge to adjust for flow-related variability if the concentration-discharge relationship is significant. A model selection procedure was used to select the specific form of the flow adjustment model used.

We tested 25 parameters over variable periods of record from 1953 to 2011including discharge, temperature, in situ parameters, and select dissolved major and trace elements (Table 9). All parameters with a significant trend included meaningful seasonal adjustment, but the role of flow varied with parameter. Several trends were detected in USGS data from the Hardin gauge.

Discharge significantly decreased over the 50-year period of record, largely in line with general patterns seen across the region (Pederson et al. 2010). Water temperature (Figure 10) showed a small, but significant increase over the last 30 years, again in line with other analyses of climate change driven patterns in Montana (Pederson et al. 2010, Isaak et al. 2011). Water temperature varies markedly on a daily basis and we only

Table 8. Date of first freeze or thaw for water years, 2001-2010 on the Little Bighorn at LIBI. Dates are from the NPS WRD gauge and the SEI logger (2010).

Water Year	Freeze	Thaw
2002	November 27	April 4
2003	November 25	March 19
2004	November 4	March 12
2005	November 28	February 24
2006	November 29	--
2007	November 25	--
2010	November 11	February 22

Table 9. Results of the seasonal Kendall test for trends in discharge and select constituent concentrations on the Little Bighorn River using data from the Hardin USGS gauge. **Bold type** indicates statistically significant trend models at p<0.10 in constituent concentration (or loading if flow adjustment is significant).

Parameter	Unadjusted Trend	Unadjusted p-value	Flow-adjusted Trend	Flow-adjusted p-value	Flow Model #; p-value	# of Seasons	Period of Record
Discharge (cfs/yr)	**-0.71**	**0.10**	--	--	--	6	1953-2011
Temperature, mean (ºC/yr)	**0.006**	**0.03**	0.02	0.23	**7; 0.05**	6	1972-2010
pH (standard units/yr)	**0.017**	**0.001**	**0.017**	**0.002**	**4; <0.001**	1	1970-2009
Acid Neutralizing Capacity	1.50	0.20	1.57	0.32	**5; <0.001**	6	1970-1979*
Hardness, (mg/L as $CaCO_3$/yr)	**6.0**	**0.01**	**6.22**	**0.02**	**5; <0.001**	6	1970-1979*
Conductivity (µmhos/yr)	**-4.16**	**0.004**	**-4.03**	**0.004**	**15; <0.001**	6	1970-2010
Total Suspended Sediment (daily) (mg/L/yr)	-3.1	0.91	-5.08	0.40	**1; <0.001**	6	1970-1977*
Suspended Sediment <0.0625mm (mg/L/Yr)	**-1.0**	**0.08**	--	--	**11; ns**	11	1993-2001
Calcium, dissolved (mg/L/yr)	**2.0**	**0.008**	**2.18**	**0.009**	**4; <0.001**	6	1970-1980*
Sulfate, dissolved (mg/L/yr)	**5.0**	**0.16**	**4.13**	**0.07**	**5; <0.001**	6	1970-1980*
Chloride, dissolved (mg/L/yr)	0.10	0.17	0.08	0.19	**8; <0.001**	6	1970-1980*
Iron, dissolved (µg/L/yr)	/	/	-0.006	0.88	**TBR; 0.01**	6	1970-1978*
Fluoride, dissolved (mg/L/yr)	0	0.23	--	--	1; ns	6	1970-1980*
Potassium, dissolved (mg/L/yr)	0	0.86	0.007	0.88	**6; <0.001**	6	1970-1980*
Magnesium, dissolved (µg/L/yr)	0	0.86	0.007	0.88	**5; <0.001**	6	1970-1980*
Manganese, dissolved (µg/L/yr)	**-0.25**	**0.01**	--	--	TBR; ns	6	1970-1978*
Sodium, dissolved (mg/L/yr)	0	0.93	--	--	1; ns	6	1970-1978*
Ammonium, dissolved (mg/L/yr)	0.10	0.15	--	--	TBR; ns	6	1993-1999
Nitrite, dissolved (mg/L/yr)	**0.12**	**0.03**	--	--	TBR; ns	6	1993-1999
Nitrate, dissolved (mg/L/yr)	**0.16**	**0.02**	--	--	TBR; ns	6	1993-1999
Nitrite+Nitrate, dissolved (mg/L/yr)	/	/	**0.12**	**<0.001**	**TBR; <0.001**	6	1970-1978*
Nitrite+Nitrate, dissolved (mg/L/yr)	**0.14**	**0.01**	--	--	TBR; ns	6	1993-1999*
Phosphorous, dissolved (mg/L/yr)	**-0.20**	**<0.001**	--	--	TBR; ns	6	1970-1978*
Orthophosphate, dissolved (mg/L/yr)	-0.03	0.68	--	--	TBR; ns	6	1993-1999
Silica, dissolved (mg/L/yr)	0	0.93	-0.02	0.74	**6; <0.001**	6	1970-1980*

Notes: Data are adjusted for flow when there was a significant relationship between concentration and flow; Trends are significant using an alpha <0.10; "—": not calculated; cfs/yr: cubic feet per second per year; µg or mg /L/yr: micrograms or milligrams per liter per year; µmhos/yr: microsiemens per liter per year; °C/yr: degrees Celsius per year; "*": % censored >5 but assumed to be acceptable and a seasonal Kendall test for censored data used with no flow adjustment allowed (even if flow is significant); TBR: Tobit model, slopes and p-value reported are from a Chi-square test of the model assuming a Gaussian distribution; "/" when using the Tobit model, flow adjustment must be included.

present these results given the long period of record over which some of the short-term variation in stream temperatures may be less relevant. Flow adjustment removed the significance from the model (yet the slope was still positive) suggesting that the trend in temperature may be confounded with the decreasing trend in discharge. The ESTREND models treat stream temperature more carefully than the simple analyses we present in the section above on SEI data; however, USGS sample sizes across time are still small and these results should be treated with caution.

A small upward (more basic) trend was detected for pH from 1970 to 2009. The magnitude and significance of the trend was similar between unadjusted and flow-adjusted concentrations indicating patterns in discharge were not driving this trend. The pH trend may be driven in part by the increasing temperatures seen in the Little Bighorn (higher temperatures may increase productivity, removing carbon dioxide from the water column leading to a more basic pH; Rebsdorf et al. 1991). Conductivity has decreased over the last 30 years, and small-grained suspended sediment decreased over 8 years in the late 1990s. Flow was a significant factor in the conductivity trend, but did not alter the model very much. Suspended sediment may be decreasing with decreasing flows as keeping sediment load suspended is dependent on the energy contained in higher stream flow.

For major constituents, both calcium and sulfate had increasing trends during the 1970s. Again, this trend is dated may not be very interesting for current conditions in the river at LIBI, but it provides a useful comparison if or when sufficient data are available again. The sulfate result is interesting given the emphasis on reducing sulfate emissions across the U.S. beginning in the mid-1970s with the Clean Water Act. For trace elements, only manganese had a significant decreasing trend. Several fractions of nitrogen showed small but significant increasing trends. This may reflect increasing agricultural land use in the basin during the early 1990s, however, most periods of record for these data were short and are now dated, so it is difficult to apply these patterns to current conditions on the Little Bighorn.

The results from the trend models, although limited, to the periods of record, indicate that there are complex patterns in water quality over the last two or three decades at Hardin (and likely LIBI). In particular, the temperature trend (while a small slope) reflects a possible increase of 2° or 3°C over three decades that likely has or will have real biological consequences. Similarly, the decrease in conductivity from 1970 to 2010 is fairly large, suggesting it likely reflects a meaningful trend in water physiochemistry (however, it is not entirely what the reference state for a system like the Little Bighorn, transitional between warm water turbid rivers and more dilute higher elevation streams, is). Long-term trend analyses like these models will offer insight into potential future changes in water quality from historic conditions.

Physical Habitat

Summary

In general, much of the in channel and riparian habitat at GRKO was in a reference state in 2009. Table 10 presents a simple summary with more detailed results below.

In particular, the cover of smaller substrates was well within the reference range seen across the ecoregion with bed sediments less mobile than expected, suggesting that riverbank sloughing is likely to occur at natural rates. Overall, in channel and riparian habitat at LIBI was complex relative to the ecoregion reference with a high

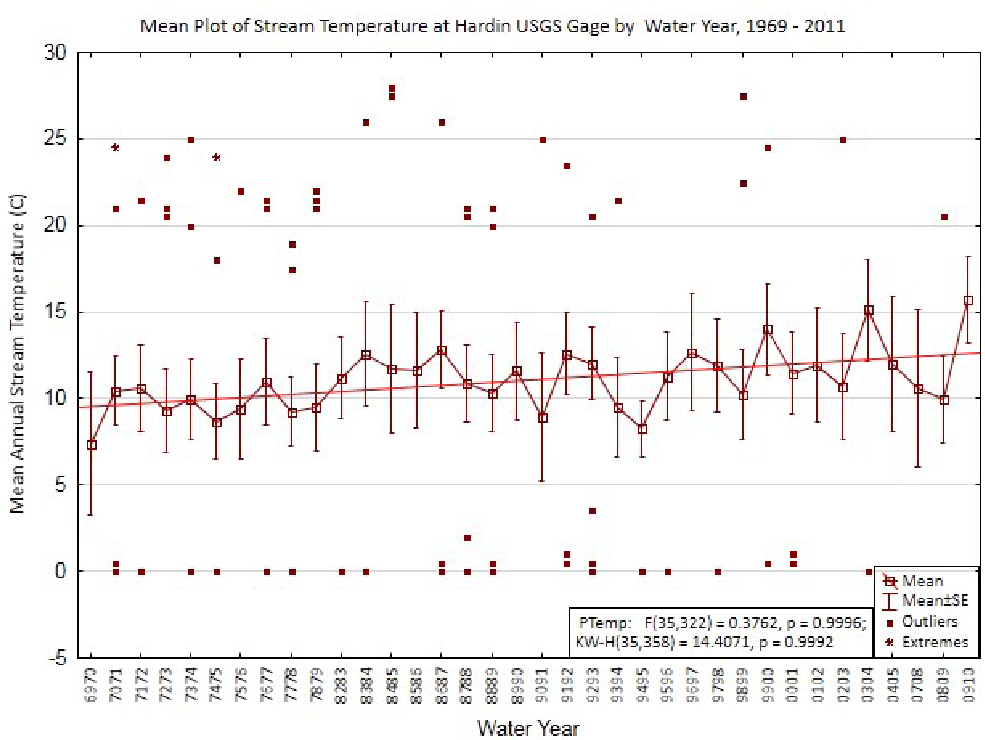


Figure 10. Mean annual stream temperature by Water Year from 1969-2010 at the Hardin USGS station. Error bars are standard errors of the mean with outliers and extreme values flagged. Note although four water years (1980, 1982, 2006, and 2007) with N<4 were removed from the analysis, some of the annual means shown here are based on small sample sizes and these data should be interpreted with caution.

Table 10. Summary condition table excerpt for select riparian and stream habitat metrics at LIBI in 2009. We include example vital signs and indicators, a brief description of results and patterns, and symbolize the status, trend, and our confidence in those summaries. See the Executive Summary for the complete Summary Condition Table.

Vital Sign (Example Indicators)	Summary	Symbol
Habitat, sediment (size, stability)	Fine substrates in the Little Bighorn channel were less prevalent than in ecoregion reference sites. Bed sediments were also slightly less mobile than expected. If we restrict data to just littoral areas, however, the cover of fines is high and may explain reduced biological condition. However, the channel bedform and these sediment dynamics are probably not relevant in ongoing natural processes like bank sloughing of concern to the park. We need more data to confirm these patterns and to assess trend.	
In stream and riparian habitat (complexity, cover, disturbance)	In-stream habitat was generally in a reference state with a fairly complex bottom profile and sufficient woody debris. However, there was more filamentous algae cover than ideal, riparian vegetation cover was patchy, especially on the west or non-park bank, and some adjacent potential stressors in the floodplain were more common than in ecoregion reference sites (even with the fairly intact riparian corridor on the park side). Invasive plants were fairly common, and some occurred with higher frequency than in ecoregion reference sites. We need more data to confirm these conclusions and assess trend.	
Habitat, stream flow (amount and timing)	Stream flow during 2007 to 2010 relative to the period of record suggest SEI monitoring occurred in variable but largely average water years. Long-term USGS gauge data suggests a shift in timing of peak flows to later in the summer, and a small but marginally significant decrease in total annual flow We have lower confidence in our assessment of stream flow at LIBI given the distance to the gauge near Hardin.	

density of (smaller) wood. There were some extensive filamentous algae which could be suggestive of nutrient input from nearby or upstream agricultural fields or other anthropogenic sources. Riparian vegetation cover was patchy, especially on the west or non-park bank, and some adjacent potential stressors in the floodplain were more common than in ecoregion reference sites (even with the fairly intact riparian corridor on the park side). Invasive plants were fairly common, and some occurred with higher frequency than in ecoregion reference sites.

The SEI data presented in this report was collected in variable years in terms of stream flow and given the importance of hydrology as a controlling variable in streams and rivers, this should be considered when assessing our results. However, over the long term, total annual stream flow may be decreasing in the Little Bighorn, but more data is needed. We do not have enough SEI habitat data to test for trend— when we do this will be a focus of SEI analyses.

Habitat Metrics and Assessment Points

Thirty-three core SEI physical habitat metrics were generated for the Little Bighorn River at LIBI from data collected during the 2009 sample event (Table 11). We chose the final metrics from the many available largely following Kaufmann et al. (1999). We interpret metrics following the general ROMN assessment approach as outlined above. Only a few have meaningful existing assessment point(s) that we felt were relevant to LIBI. We also derive assessment points for select metrics using Northern Great Plains ecoregion reference sites. For simplicity, we restrict the number of assessment points derived from ecoregion reference sites to a few key habitat metrics—others may be derived upon request or in future reports. Note that the sample size of ecoregion reference sites was a bit small (~38); however, a new data set from the EPA National Rivers and Stream Assessment program will soon be available that will improve this. We interpret habitat metrics with no assessment points using qualitative comparisons to predicted values from models or via comparisons to average conditions across reference sites in the ecoregion. All interpretations are done in the context of the ecology of the Little Bighorn River and management needs for LIBI (i.e., maintaining the historic context of the Little Bighorn battle or bank sloughing that might expose artifacts). Finally, as we accrue additional SEI data, we (will)

Table 11. Summary of core SEI physical habitat metrics for the Little Bighorn River in Little Bighorn National Battlefield, 2009. Assessment points are for reference and non-reference condition classes with the direction of inequality indicating whether the state is above or below a value. Metric values in **bold red** are in non-reference. Metric values in **bold green** are in reference. Metric values in **bold** are either intermediate or non-reference (depending on the existence of a non-reference assessment point). For additional clarifications on Table content see Notes below.

SEI Core Physical Habitat Metrics	LIBI 2009	Reference Assessment Points	Non-reference Assessment Points	EMAP Signal:Noise**
Habitat Volume				
Mean residual depth (cm)	**21.4**	>22.4[1a]	<10[1a]	10.9
Deviation in mean residual depth from expected (cm)	20.0	--	--	5.5
Habitat Complexity				
Thalweg depth coefficient of variation (dimensionless)	**0.54**	>0.39[1a]	<0.32[1a]	7.4
Volume of woody debris in the bankfull channel (m3/m2)	0.018	--	--	2.4
Number of large woody debris (pieces /100 m of channel)	3.18	--	--	4.6
Cover for Stream Biota				
Areal cover of aquatic macrophytes (%)	1.8	--	--	8.1
Areal cover of filamentous algae (detectable by the unaided eye, %)	53	--	--	0.9
Areal cover of woody debris, brush, undercut banks, overhanging veg (%)	**18**	>34[2]	<18[2]	2.6
Pool density (m of residual pool / m of sampled stream)	0.01	--	--	--
Substrate				
Streambed silt & finer (“fines,” <0.6 mm in diameter) (%)	**10.7**	<33.3[1b]	>62.8[1b]	22.2
Streambed sand & finer (<2 mm) (%)	24.1	--	--	18.3
Deviation of % streambed silt & finer from expected (“excess fines” , %)	-25.6	--	--	12.8
Deviation of % streambed sand & finer from expected (“excess sand+fines”, %)	-42.6	--	--	9.2
Deviation of log mean substrate diameter from expected (fining index, %)	0.65	--	--	9.0
Relative Bed Stability				
Mean bed particle diameter/critical (mobile) diameter at bankfull (log)	**-1.24**	F*: >-1.7[2*] A*: <-0.5[2*]	F*: <-2.5[2*]; A*: >0.3[2*]	8.7
Floodplain Interaction				
Channel sinuosity (log)	1.09	--	--	4.3
Incision from terrace to bankfull height (m)	**1.36**	<1.06[1b]	>1.5[1b]	3.9
Bankfull width/depth	75.6	--	--	6.0
Bankfull width/wetted width (flood inundation potential)	1.04	--	--	6.9
Hydrologic Regime (Habitat Based)				
Base flow/annual mean runoff (inverse index of “droughtiness”)	0.016	--	--	0.8
Bankfull depth/wetted depth (morphometric index of “flashiness”)	38.8	--	--	4.7

Table 11. *Summary of 32 core SEI physical habitat metrics (continued).*

SEI Core Physical Habitat Metrics	LIBI 2009	Reference Assessment Points	Non-reference Assessment Points	EMAP Signal:Noise**
Riparian Vegetation Cover				
Canopy density (measured at the bank, %)	15.78	--	--	34.8
Riparian canopy+mid+ground layer vegetation (%)	112	--	--	3.8
Riparian canopy+mid+ground layer woody veg (%)	**47**	>35[2]	<15[2]	8.0
Human Disturbances				
Riparian & near-stream agriculture—all types (proximity weighted index)	0.58	--	--	2.8
Riparian & near-stream roads (prox. Weighted index)	0.21	--	--	6.0
Riparian & near-stream rowcrop agriculture (prox. Weighted index)	0.28	--	--	11.2
Riparian & near-stream walls, dikes, revetment (prox. Weighted index)	0.0	--	--	1.6
Human disturbances of all types (prox. Weighted inverse index)	0.41	--	--	4.2
Riparian vegetation alteration (prox. Weighted inverse index)	**0.01**	>0.03[1a]	<0.015[1a]	16.6
Frequency of individual invasive plants	See Table 10	--	--	--
Frequency of all target invasive plants	1.54	--	--	--

Notes

[1a] Assessment points generated from reference sites in the Northwestern Great Plains ecoregion for indicators where decreasing value is associated with a declining condition at the >50th/<25th percentile values for reference/non-reference, respectively

[1b] Assessment points generated from reference sites in the Northwestern Great Plains ecoregion for indicators where increasing value is associated with a declining condition and assessment points in ecoregion reference site distribution are at the <50th/>75th percentile values for reference/non-reference, respectively

[2] Assessment points from Stoddard et al. (2005), the first value is the assessment point for the reference state and the second non-reference. The direction of the inequality indicates the direction of the relationship.

* Assessment points values for RBS are given for fining (F) and armored (A) channels for reference and non-reference states (see Figure 13).

P=Comparison to a predicted value corrected for geoclimatic context (not necessarily a reference assessment point)

** S:N is the ratio of information to noise in a metric. Higher S:N values suggest the metric had more signal or true information than variation due to crews, season and other sources (see text and Kaufmann et al. 1999, Stoddard et al. 2005). S:N source data are from EMAP sites in a broader bioregion (“Plains”).

generate baselines to compare change in and eventually trend in habitat condition.

Quality Assurance and Quality Control

We only have habitat results from one full sample event at LIBI and therefore have no estimates of spatial or temporal variability (while SEI habitat data has many internal subsamples or replicates, the proper scale for SEI habitat data and metrics is the complete sample reach). Until we generate our own QAQC data, as a rough proxy of precision in our habitat metrics we include estimates of variability from the EMAP program (see above) and discuss them in relevant sections below.

Habitat Volume

Habitat volume, or the amount of in-channel habitat available to stream biota, is a major determinant of the quality of a stream. The general size of a stream is a function of its drainage area and discharge throughout the year; however, anthropogenic activities frequently alter channel dimensions and flood or low flow discharge, all of which can alter the quantity and quality of aquatic habitat.

SEI data can be used to generate simple metrics of habitat volume such as mean wetted width and depth. While useful, these metrics are sensitive to the flow stage on the given day of sampling and do not necessarily reflect habitat volume during limiting drought conditions. Therefore, we estimated a residual mean depth metric that accounts for stream flow (following Kaufmann 1987, Stack 1989, and Kaufmann et al. 1999). Mean residual depth is the mean across the sampled reach in the difference in depth or bed elevation between a pool and its downstream riffle crest (i.e., hydraulic control point). This metric is independent of instantaneous discharge as it is based on the profile of the stream bottom along its deepest point (regardless of how much water is in the channel). Reach-wide residual mean depth varies naturally across references streams as a function of stream size and other geomorphological attributes. However, within these natural gradients, Kaufmann et al. (2008, 2009) demonstrate that anthropogenic stressors also play a strong role in the size and shape of streambeds and sediment dynamics such that metrics like residual mean depth are somewhat independent of stream size (but see below). Therefore, while caution must be used, ecoregion reference values generated from ecoregion reference sites that span a wide range in stream type and watershed size are likely appropriate (Kaufmann et al. 1999, Stoddard et al. 2005). The mean residual depth at LIBI in 2009 of 21.4 cm was below the ecoregion reference assessment point (50th percentile) of 22.4 cm but well above the non-reference (25th percentile) of 10 cm (Table 11). This suggests that mean residual depth at LIBI in 2009 was just below the reference assessment point, or that at low flow there may be slightly less habitat than ideal. However, there is more habitat volume than in non-reference sites across the ecoregion or likely a meaningful amount of residual habitat volume in the channel, even at lower flows of the Little Bighorn.

Mean residual depth is controlled to a large degree by the size and power of the stream, which in turn vary with geoclimatic setting (i.e., drainage area, runoff, and slope; Stack and Beschta 1989). Therefore, another useful metric for understanding habitat volume is the deviation of mean residual depth from a predicted value that accounts for geoclimatic setting. This metric may better deal with the confounding effects of stream type and watershed size on residual volume. We estimated the predicted mean residual depth at LIBI as 1.07 cm using a model developed by the EPA (Stoddard et al. 2005). The model was derived from data collected by EMAP at over 1,000 streams across the West and predicts mean residual depth from basin area, long-term mean annual precipitation, channel slope, and lithology. *It is important to note that this predicted value is not necessarily a reference condition (as used in other interpretations of SEI data). The EPA model is based on streams and rivers ranging from pristine to disturbed, it merely corrects for geophysical drivers*. The deviation of the measured mean residual depth at LIBI in 2009 from its predicted value of was 20.0 cm. A value of zero would suggest the Little Bighorn had a mean residual depth exactly as predicted or expected given the geoclimatic setting of LIBI. The large amount of residual habitat volume relative to what is expected based on geoclimatic setting further suggests that even at low flow there are likely to be remnant pools available for fish and other stream biota.

Signal to Noise Ratio

The S:N of both the predicted (or scaled) and unscaled habitat volume metrics was acceptable within the EMAP program, with high values suggesting that they are estimating conditions in LIBI with acceptable precision. It is more difficult to count wood within volume (size) classes as required for the volume metric.

Habitat Complexity

All else being equal, more complex river habitat should generally support greater biodiversity and a more intact, higher functioning system (Gorman and Karr 1978, Benson and Magnuson 1992). Habitat complexity is difficult to quantify, yet SEI protocols provide for several metrics that may reasonably estimate this attribute of rivers. We selected three to interpret here: (1) coefficient of variation in thalweg depth, (2) the volume of woody debris per m2 of bankfull channel, and (3) the density of large wood (Kaufmann 1993, Stoddard et al. 2005).

The coefficient of variation in thalweg depths directly measures how variable (or complex) the bottom of a river is. Higher values (on a scale of 0 to 1.0) suggest greater dispersion among replicates of thalweg depth (or a more complex channel profile). The thalweg profile coefficient of variation at LIBI was 0.54 (Table 11). There are no assessment points or predicted values available for this metric. Therefore, we compared the LIBI value to assessment points from the distribution of reference sites from across the ecoregion (50^{th} percentile for reference=0.39; 25^{th} percentile non-reference=0.32; Table 11). The LIBI value was in the 80th percentile of the reference distribution, well above the reference assessment point. This suggests that habitat complexity from variation in bottom depths is high, likely enhancing condition in the Little Bighorn.

Woody debris is one of the most important sources of structure and complexity in most stream types (Figure 11; Harmon et al. 1986, Robison and Beschta 1990) and we used two woody debris metrics as estimates of habitat complexity. First, we used the volume of woody debris per m^2 of bankfull channel. This metric incorporates both the frequency and amount of wood of any size. We use a raw value versus the log, as used in Stoddard et al. (2005), to more intuitively include rivers with no (or zero) wood volume (where a log value is undefined). The Little Bighorn River at LIBI had a volume of large woody debris (LWD) per area of bankfull channel of around 0.018 m^3/m^2 (Table 11). There are no established assessment points available for this metric. In qualitative comparisons (using EMAP data), the Little Bighorn at LIBI appears to have more total wood volume than reference sites across the ecoregion (the mean wood volume across ecoregion reference sites was 0.003 m^3/m^2, with a standard deviation of 0.002). Second, we used the density of large wood (>0.3 m in diameter and >5 m in length). This metric focuses on the simple count (expressed per unit area sampled) given the importance of (and often rare) larger woody debris in plains rivers like the Little Bighorn. The density of larger woody debris was 3.18 per 100 m of river at LIBI. There are no established assessment points available for this metric. In qualitative comparisons (using EMAP data), the Little Bighorn at LIBI appears to have lower large wood density volume than reference sites across the ecoregion (the mean large wood density across ecoregion reference sites was 5.9 per 100 m of river, with a standard deviation of 3.3). These results suggest that supply of large wood to the Little Bighorn, which depends on active floodplains that move naturally eroding banks that then deliver more substantial woody debris to a channel, may be less intact (but note the large standard deviation around the ecoregion mean value). However, total wood volume (across all sizes) was higher than in ecoregion reference sites, perhaps because of increased amounts of smaller woody debris input given the protected status of the banks on the LIBI side of the river. The

LIBI sample reach travels through a fairly heterogeneous floodplain. The southern end is within larger bluffs with uplands prairie on top and woody input to the channel is low (M. Stichmann, pers. comm., 2012). The middle and northern portion of the reach moves through a broader floodplain with more riparian vegetation, especially on the right bank (see Figure 11).

Signal to Noise Ratio

The S:N of the habitat complexity metrics was generally acceptable within the EMAP program, with high values for thalweg depth variation and woody debris density, but only a moderate value for woody volume; it is more difficult to count wood within volume (size) classes as required for the volume metric. This suggests that these metrics may have mixed capacity to estimate river habitat complexity in LIBI with acceptable precision.

Cover for River Biota

Another metric used to characterize the sAnother key function of stream habitat is the support of aquatic biota through physical cover (i.e., for protection from predators or as spawning habitat). While several of the habitat metrics we interpret in this report are indirectly related to this function, following Stoddard et al. (2005), Hankin and Reeves (1988) and Kaufmann and Whittier (1997), we focus on four direct metrics of in-channel cover. These include: (1) the cover of aquatic macrophytes, (2) the cover of filamentous algae, (3) the combined cover of all natural features typical of lower gradient rivers like the Little Bighorn, and (4) pool density.

In qualitative comparisons (using EMAP data), the Little Bighorn at LIBI tended to have low cover of macrophytes compared to that seen in reference sites across the ecoregion. While excessive macrophytes can be problematic (indicating excess nutrients or reduced stream flow), the very small cover at LIBI suggests that there may have been a lack of this cover type for fish and other biota in the channel. Attention should also be paid to the types of macrophyte species present. Northern water milfoil (*Myriophyllum* spp.; DiTomaso and Healy 2003) is extremely common throughout the Montana plains. In stream sites where high nutrient enrichment is occurring, a near-complete replacement by Coontail (*Ceratophyllum demersum*) often occurs. Coontail is a rootless, free floating macrophyte can proliferate in streams that are being heavily loaded with nutrients (DiTomaso and Healy 2003). In this sense,

Figure 11. ROMN and LIBI field crew collect river physical habitat data from a raft on in the Little Bighorn River in 2008. The area in the photo shows good examples of large woody debris, complex bank morphology and riparian cover.

it is similar to floating and benthic algae in that it relies on water-column nutrients for growth, since it does not take up nutrients from the sediment through its roots like other macrophytes. It is readily identified and can be distinguished from northern water milfoil with a field identification guide. Choking mats, or its presence to the exclusion of other macrophytes, should be taken as a strong indicator of nutrient over enrichment. Future work in LIBI should include identification of any macrophytes found.

Filamentous algae cover was nearly five times the mean ecoregion value (53% vs. 14%). Filamentous algal beds can be important habitat for small fish, but the high cover at LIBI was excessive. Suplee (2008) suggests that in the Northwestern Glaciated Plains ecoregion (the high-line region of the state to the north of LIBI), streambed cover by filamentous algae should generally be less than 30% for a single sampling event and less than 25% for the summertime average. Cover at LIBI in 2009 far exceeded these values.

An assessment point from Stoddard et al. (2005) for the fourth metric (natural cover types including woody debris, brush, undercut banks, and overhanging vegetation) suggests reference rivers should have more than 34% proportional cover from natural features. At LIBI this cover was only 18%—just at the point for a non-reference state suggesting that there was reduced natural cover.

Measured pool density on the on the Little Bighorn was just under 0.01 per meter of stream. There are no established assessment points or regulatory criteria available for this metric relevant to the Little Bighorn. In qualitative comparisons (using EMAP data), the Little Bighorn at LIBI had higher pool density compared to reference sites across the ecoregion (0.01 vs. 0.007; Table 11). In general, we do not think a lack of pool habitat as cover for river biota in the Little Bighorn at LIBI is of concern.

<u>Signal to Noise Ratio</u>

The S:N of the cover for river biota metrics was variable within the EMAP program, with low values for algae cover, a moderate value for cover of woody debris/brush/undercut banks/overhanging vegetation, and a high value for macrophytes. This suggests that these metrics may have mixed capacity to estimate conditions in LIBI with acceptable precision. Algal cover can vary naturally over time and some natural features can be hard to safely estimate with precision in challenging river habitats.

Substrate

River substrates are major components of in-channel, shoreline and bank habitat and can be key elements of overall stream condition. Sediment loads play an important role in fluvial processes that can lead to bank sloughing (potentially exposing artifacts from the battle; Figure 12). Streams and rivers in the Great Plains of Montana often flow through highly erodible soils, which can contribute to naturally high sediment bedload, shifting channels, few riffles, silt and clay substrates, and turbid water (Moody et al. 1999, Pizzuto 1994, Bramblett et al. 2003). Because anthropogenic sediment sources can mimic natural conditions in plains streams, differentiating between natural and human caused in-stream sediment conditions is especially challenging (Bramblett et al. 2003). However, there are important anthropogenic sources of excess sediment in plains streams and sediment metrics are still useful for understanding the condition of the Little Bighorn. State of Montana standards for sediment that are relevant for eastern Montana are narrative and generally that state that there are to be no increases above naturally occurring concentrations (MT DEQ 2002). As this is vague we derive select assessment points from ecoregion reference sites.

Substrate size can impact the species composition of macroinvertebrate, periphyton, and fish assemblages (Hynes 1972, Cummins 1974, Platts et al. 1983, Barbour et al. 1999). Along with bedform, substrate particle size influences the hydraulic roughness, water velocity, and the interstices amongst substrate particles that provide habitat for macroinvertebrates and smaller vertebrates. The sizes of substrates and their relative extents on riverbeds are

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Figure 12. Sloughing banks on the Little Bighorn in 2009 (top), 2011 (above), and an aerial view using imagery from 2004 (right). This location is upstream of the SEI sample reach, but similar in many aspects and failure of this bank might change habitat conditions within the SEI reach.

often sensitive indicators of the effects of human activities on rivers (MacDonald et al. 1991, Barbour et al. 1999). Accumulations of fine substrate particles can fill interstitial spaces and reduce habitat space for benthic fish, macroinvertebrates, and diatoms (Platts et al. 1983, Rinne 1988). In addition, fines impede the circulation of oxygenated water into hyporheic habitats. Decreases in the mean particle size and increases in riverbed fine sediments can destabilize river channels (Wilcock 1997, 1998) and may indicate increases in the rates of upland erosion and sediment supply from anthropogenic disturbances (Lisle 1982, Dietrich et al. 1989). Because of these and many other important aspects of stream substrate, we include five substrate metrics following Stoddard et al. (2005), and Kaufmann et al. (1999): (1) percent silt and finer ("fines;" <0.6 mm), (2) percent sand and finer (<2 mm), (3 and 4) the deviation of fines and sand from predicted values, and (5) deviation of the log mean substrate diameter from expected ("Fining Index"). Note that we calculate percent fines and percent sand differently than Kaufmann et al. (1999) by including both littoral and thalweg substrate data. We feel this makes the metric more comparable across wadeable and boatable stream sites.

Percent fines at LIBI was 10.7% in 2009 (Table 11). This is below the ecoregion reference (50th percentile) of 33.3 and well below the 75th percentile for non-reference of 62.8. Because increasing percent fines are associated with a declining condition this places LIBI well within the reference portion of the distribution derived from ecoregion reference sites. Similarly, the percent of sand and finer sediments at LIBI in 2009 was 24.1%—below the ecoregion reference site mean of 45.5% and suggests a level of small sediments at LIBI comparable to ecoregion reference conditions. These results are somewhat surprising as visually the Little Bighorn appears to be more of a fine-sediment-laden system, at least on its banks. However, the deeper portions of the Little Bighorn channel do have larger substrates and by modifying the structure of these metrics through inclusion of substrate counts from the thalweg, we feel we more accurately estimate substrate composition for the river as a whole (the ecoregion reference site values are generated using the same approach). However, as presented below, we do see a biological response to sediment in select metrics derived from macroinvertebrates and diatom assemblages at LIBI. This apparent mismatch may simply be because most biological subsamples come from the river margins (due to safety concerns) where there are more fine sediments. Trends in suspended sediments (small sediments in the water column) show a meaningful decrease from 1970-1977 and from 1993-2001 (using USGS data). There were also relatively low levels of TSS in 2007-2010 SEI data. Therefore it may be possible that sediment are on the mend at LIBI.

Substrate sizes and density vary naturally in streams with different drainage areas, slopes, and surficial geologies (Leopold et al. 1964, Morisawa 1968). Therefore, other useful metrics for understanding sediment are the deviation of percent fines, sand and mean substrate size from predicted values that account for geoclimatic setting (Kaufmann et al. 2008). To estimate predicted values we use models derived from data collected by EMAP at over 1,000 streams across the West. The models predict values based on bankfull bed shear stress (see below), catchment mean annual precipitation, ecoregion type, and the method used to quantify the bed substrate. It is important to note that predicted values are not necessarily a reference condition (as used in other interpretations of SEI data). The EPA models are based on streams and rivers ranging from pristine to disturbed, they merely correct for geophysical drivers. The deviation of percent fines and percent sand from their predicted values was -25.6 and -42.6, respectively (Table 11). A value of zero would suggest the percentage of each substrate size was as predicted or expected, given the geoclimatic setting. Interestingly, the large negative values suggest that LIBI had a lower measured percentage of these small sediment size classes than expected based on the geoclimatic setting of the Little Bighorn (or in other words, there should be more fines and sands at LIBI). However, the deviation from the predicted mean substrate size was 0.65 (Table 11), suggesting that typical sediment size was a bit larger than expected. Sediment size in the Little Bighorn was somewhat bimodal, with both small size classes and larger cobble and above sized particles.

In general, we interpret sediment results for LIBI as suggesting that there is not a sediment problem and that there may even be "room for more small sediments" in the channel (such that the deviation from the predicted values would be closer to zero). In combination with data and interpretation presented below on relative bed stability and bank structure, our results do not suggest any important imbalance in sediment supply and transport in the river. This suggests that bank sloughing is likely occurring at a natural rate that is largely dependent on stream discharge, bank soils, and vegetative cover. Unless a major intervention is initiated, banks will continue to slough and the river will do what rivers like the Little Bighorn have always done, which is to move about their floodplain. On the length of the river that runs along the boundary of the Custer Battlefield unit, there is a well-developed meander that is very close to being abandoned through channel migration (see Figure 12). The alluvial deposit through which this meander is cutting may contain cultural artifacts that would be lost as a result of channel migration (Martin 2010) and oxbow formation. On May 13, 2010, an interdisciplinary team of natural resource specialists; an archaeologist; and hydrologists from Little Bighorn Battlefield National Monument, Bighorn Canyon National Recreation Area, and the NPS Water Resources Division evaluated ongoing channel migration, the presence of cultural material in the eroding alluvial deposit, and the feasibility of various stabilization treatments (Martin 2010). The team concluded that, overall, the river displays the elements of a properly functioning meandering stream. The observed erosion and channel migration is predominantly a natural process consistent with meandering river evolution. Ultimately, the meander of interest will form an oxbow. An investigation of the oxbows within LIBI conducted in July 2010 found no archaeological materials predating the late nineteenth century in any of the three oxbows within the Custer Battlefield unit (Scott 2010), however, artifacts in ravine areas could be buried (due to years of natural erosion) below what is detectable with current archaeological instruments.

Signal to Noise Ratio

The S:N of the both the unscaled and predicted bed particle size metrics was easily adequate within the EMAP program, suggesting that they are estimating conditions in LIBI with acceptable precision. For the predicted or scaled metrics, this is despite removing the portion of the variance in bed particle size due to natural geomorphic variability.

Relative Bed Stability

Another metric used to characterize the substrate of the Little Bighorn is relative bed stability (RBS). RBS measures the tendency of streambed particles to resist transport under a given streamflow condition. Basically, the metric compares the measured median substrate size in the streambed to the maximum substrate size carried during bankfull events. In other words, if a stream is capable of moving large boulders during bankfull flow events, yet the measured median substrate is fines and silts, a RBS metric would suggest that excessive fine sediment loading is present. RBS is a critically important component of habitat structure for aquatic organisms. Species are adapted to natural streambed movement—too much or too little can cause stress and led to reduced stream condition. Finally, because RBS depends on both the supply of sediment and the capacity for sediment to be transported, it may have a direct connection to many anthropogenic disturbances.

Values of RBS for a given stream type and geoclimatic setting can be either to low (finer substrates with a more unstable streambed) or to high (coarser substrates and to stable of a streambed) than expected (given the complex placement of reference assessment points on both ends of the scale of RBS, Figure 13 shows these values graphically). Lower than expected streambed stability may result either from high inputs of fine

Figure 13. Clarification on arrangement of finning and armoring assessment points for relative bed stability (log RBS; Stoddard et al. 2005). Unlabeled yellow regions are intermediate between reference and non-reference states. Black arrow indicates approximate location of 2009 LIBI RBS value.

sediments (i.e., when the anthropogenic supply of sediments from the landscape exceeds the ability of the stream to move them downstream) or increases in flood magnitude or frequency. Low RBS resulting from hydrologic alteration can be a precursor to channel incision. In contrast, high bed stability is typified by hard, armored streambeds, such as those often found below dams where fine sediment flows are interrupted, or within channels where banks are highly altered (e.g., paved or lined with rip-rap).

In 2009, the observed mean particle size at LIBI was 8.5 mm and the estimated critical maximum mobile diameter was 126.9 mm. RBS at LIBI (by convention this is expressed as a log; RBS=-1.24) was in a reference condition based on assessment point values developed by Stoddard et al. (2005) for plains type rivers (Table 11 and Figure 13). This suggests that riverbed substrates at LIBI were appropriately mobile. This is in spite of the lower fourth of the LIBI sample reach having rip rap on the park (right) bank (placed to protect the oxbow from further cutting toward the pump house on this meander; M. Stichmann, pers. comm., 2012).

Signal to Noise Ratio

The S:N of the RBS metrics was high within the EMAP program, suggesting that it is estimating conditions in LIBI with acceptable precision.

Floodplain Interaction

Following Stoddard et al. (2005), Madej (2001) and Kaufmann et al. (1999), we use four metrics to estimate the interaction between the Little Bighorn channel and its floodplain at LIBI. These include: (1) channel sinuosity, (2) incision, (3) bankfull width to depth ratio, and (4) bankfull width to wetted width ratio.

Channel sinuosity of a stream or river reach is the ratio of channel length (as the water flows) divided by the straight-line distance between the two ends of a sample reach. It ranges from 1.0 (straight) to around 3.0 (tortuously twisty). Channel slope should be considered when interpreting sinuosity as very steep channels are more likely to be straight naturally (the Little Bighorn is fairly flat so this is less relevant). The greater the sinuosity, the slower water flows through a valley and the more chance it has to interact with the terrestrial landscape. Channel straightening decreases sinuosity, increases channel slope, and can lead to lower bed stability, greater sediment transport, increased bank instability, channel downcutting, and downstream flooding. There are no assessment points or predicted values available for this metric. In qualitative comparisons to EMAP data, the Little Bighorn at LIBI in 2009 had slightly lower sinuosity (1.09) than reference sites across the ecoregion (mean log sinuosity=1.25, SD=1.0). However, at this point, it is unclear if reduced sinuosity at LIBI is any cause for concern. The scale of the SEI sample reach may not be quite large enough to appropriately measure this attribute of the Little Bighorn (a larger river that will express its sinuosity across a larger reach). KellerLynn (2011) presents data and a discussion of larger-scale floodplain morphology of Little Bighorn at LIBI. In summary, at larger scales the river has been able to maintain a very sinuous and well-developed meander pattern, despite losing a portion of the valley's width to infrastructure. The primary meander belt has occupied the river-right side of the valley since the time of the Battle of the Little Bighorn (Martin 2010). The river continues to rework the older deposits in the river valley, abandoning established meanders and forming new ones. Evidence of this ongoing process is readily apparent in satellite imagery, aerial photos, and published maps, where numerous meanders and oxbows are visible (Martin 2010; see Figures 2 and 3). Moreover, recent changes in vegetation at the apex of several meanders within or near the LIBI sample reach suggest several meanders are increasing in width. Reworking of the channel during a 2011 flood increased the apex noticeably (M. Stichmann, pers. comm., 2012).

River incision results when bankfull stage is at a lower elevation than the top of either stream bank and is usually caused by an increase of the erosive ability of a river, a decrease in the bedload sediment supply, or when the stream bottom and banks are destabilized by disturbances. There are no assessment points or predictive EPA models available for this metric. Therefore, given the importance of incision to many aspects of stream habitat condition (Kaufmann et al. 1999) we compared incision at LIBI (1.36 meters in 2009) to assessment points from the distribution of reference sites from across the ecoregion (50^{th} percentile for reference=1.06; 75^{th} percentile non-reference=1.5; note that increasing incision is associated with a declining condition so a reference state is below the 50^{th} percentile and a non-reference is above a 75^{th} percentile). Incision at LIBI was in the 70^{th} percentile of the reference distribution, or intermediate between the ecoregion reference and non-reference assessment points (but closer to a non-reference condition). This result is consistent with the agricultural land use in the Little Bighorn watershed. Incision can be caused by local or upstream disturbance such as grazing of riparian vegetation that protects river banks and channels. It is one of the few metrics we generated that suggests that fluvial processes on the Little Bighorn are not in a reference state. However, we caution that our methods are general and it is sometimes difficult to estimate incision from the water as the SEI non-wadeable protocol specifies.

Our last two metrics of the interaction between the Little Bighorn and its floodplain, bankfull width to depth ratio and the bankfull width to wetted width ratio, are relatively simple measures of the response of the channel to changes in sediment supply and transport. Channels that are over widened relative to their depth are often associated with excess sediment deposition and streambank erosion, contain shallower and warmer water (White et al. 1987), and provide fewer deep water habitat refugia for fish (MT DEQ, 2011c; Kasahara and Wondzell 2003). There are no established assessment points or regulatory criteria available for these two metrics, and we only make qualitative comparisons to values across the ecoregion (using EMAP data). The bankfull width-to-depth ratio at LIBI in 2009 (75.6) describes a wide, fairly shallow channel, notably larger than the mean ecoregional reference site value of 9.5 (SD=1.1). Wider bankfull channels relative to their wetted width often are related to higher fine and smaller sediments and steep incised banks. The bankfull width to wetted width ratio (1.04) was fairly low relative to the ecoregional reference mean of 1.65 (SD=1.0). In general, both of these metrics suggest that the Little Bighorn had more constrained access to the flood plain in 2009.

Signal to Noise Ratio

The S:N of the floodplain interaction metrics was moderate within the EMAP program, suggesting that they are likely estimating conditions in LIBI with acceptable precision.

Hydrologic Regime (Habitat-Based)

The hydrologic regime, or the amount and timing of streamflow, and its interaction with other elements of river habitat is a fundamental component and determinant of the condition of rivers. For example, human use of water in rivers like the Little Bighorn (i.e., withdrawal for irrigation) can cause stress to river ecosystems (Poff et al. 1997) when changes in hydrology disrupt reproduction, survival, spawning, and migration of biota (Poff and Ward 1989, Junk et al. 1998).

Following Stoddard et al. (2005), we use two general metrics derived from habitat data as indirect indicators of the hydrologic regime. These are in addition to the direct measure of stream flow using USGS data from the nearby gauge as presented below. The habitat based measures include: (1) the ratio of base flow to annual mean runoff, and (2) the ratio of bankfull depth to wetted depth (both at the time of sampling). The first index is an index of "droughtiness" that compares instantaneous discharge (corrected for watershed area) to the average annual runoff (using a model developed by Wolock and McCabe (1999) and precipitation, evapotranspiration, topographic data from 1951-2000 within the Little Bighorn watershed). If the instantaneous baseflow is high relative to the average, the site is likely not experiencing a drought. The second index is a morphometric index of "flashiness." It estimates a range or the degree of variation in a sites hydrologic regime by comparing high and low flows with bankfull depth as the high flow proxy and wetted depth at base flow as the low flow proxy. If the ratio of high to low flow is high, peak flow is much greater than baseflow suggesting the channel experiences more significant flooding and is more flashy (or variable) in its hydrology. Both of these metrics are somewhat crude approximations, yet they may add a more integrated perspective to the classic measures of hydrology (i.e., stream discharge) we also utilize. Their primary value may be from simple comparisons to ecoregional reference data and in future trend analyses.

There are no established assessment points or regulatory criteria available for these two metrics, and we only make qualitative comparisons to values across the ecoregion (using EMAP data). The Little Bighorn at LIBI had a ratio of base flow to annual mean runoff in its watershed of 0.016. This suggests that in 2008 the river had reduced "droughtiness" relative to the mean across ecoregion reference sites (0.002) or that potential water stress or localized drought at LIBI was relatively minor in 2009 (this generally matches the hydrograph for the year when compared to the 30-year normal). The ratio of bankfull to wetted depth or flashiness index of the Little Bighorn at LIBI in 2009 (38.8) was higher than at ecoregion reference sites (7.98), suggesting that the river was flashier than reference sites in the ecoregion. The cause of this is unclear. It might be the larger size of the river or the more mountainous nature of its upper watershed where floods might have more energy than in lower gradient systems.

Signal to Noise Ratio

The S:N of the habitat-based hydrologic regime metrics was very low for the droughtiness index, but acceptable for the flashiness index within the EMAP program, suggesting that they are estimating conditions in LIBI with mixed precision. The droughtiness index uses instantaneous discharge which can vary naturally over short time periods.

Riparian Vegetation Cover

The importance of riparian vegetation to channel structure, cover, shading, nutrient inputs, large woody debris, wildlife corridors, and as a buffer against anthropogenic disturbance is well recognized (Naiman et al. 1988, Gregory et al. 1991). Riparian vegetation can moderate river temperatures through shading, increase bank stability and provide inputs of coarse and fine particulate organic material. Organic inputs from riparian vegetation become food for river organisms and provide structure that creates and maintains complex channel habitat.

Largely following Stoddard et al. (2005) and Ringold et al. (2008) we used three metrics to describe the riparian vegetation of the Little Bighorn at LIBI. These include; (1) canopy density at the bank; (2) total riparian vegetation areal cover in the canopy, mid-level, and ground layers; and (3) total riparian woody vegetation areal cover in the canopy, mid-level, and ground layers. We use canopy density at the bank (versus midstream as in Stoddard et al. 2005) because it is more appropriate for larger rivers such as the Little Bighorn where even reference systems will often not have a closed canopy over the middle of the river (Vannote et al. 1980).

There are no established assessment points or regulatory criteria available for the first two of these metrics, and we only make qualitative comparisons to values across the ecoregion (using EMAP data). The Little

Bighorn at LIBI had lower canopy density on its banks than the mean across ecoregion reference sites (15.78 vs. 61.8% (SD=1.6); Table 11). The LIBI sample reach is on the border of the park with the left bank bordered by private land with extensive row crop agriculture and pasture (Figure 14). These land uses tend to reduce vegetative cover on the banks relative to the park side of the reach with a largely intact riparian system. The lack of canopy may contribute to potentially elevated temperatures in the channel that can have important impacts on many aquatic species. However, total riparian vegetation cover (versus just on the banks and in the canopy) was more comparable to the ecoregion reference mean (112 vs. 106% (SD=3); Table 11). The banks of the Little Bighorn do tend to have high ground cover of forbs and grasses, making up for lower cover in the mid and upper canopy. The third metric in this group, total riparian woody cover, was above a reference assessment point from Stoddard et al. (2005). There is a robust upper canopy on the park side with high woody cover in the mid-level and canopy layers. Woody cover is an important potential source of nutrients and structure and at least the park side of the reach likely contributes to the condition of the river.

Signal to Noise Ratio

The S:N of the riparian vegetation metrics were all high within the EMAP program, suggesting that they are likely estimating conditions in LIBI with acceptable precision. In particular, the instrument aided canopy density metric was very precise (S:N=34.8).

Human Disturbance

Following Stoddard et al. (2005), Ringold et al. (2008), and Kaufmann et al. (2008), we used eight metrics describing disturbances and alteration to riparian vegetation on the banks of the Little Bighorn at LIBI. These include: (1) proximity weighted tallies of riparian and near-river agriculture (of all types), (2) rowcrop agriculture, (3) roads, (4) walls/dikes/revetments, (5) an *inverse* index of human disturbances of all types combined, (6) a riparian vegetation alteration metric, (7) frequency of select target invasive species, and (8) all target invasive plants in riparian plots.

Anthropogenic disturbances in riparian systems have long been considered important stressors on river habitat condition (i.e., Patten 1998). Important potential anthropogenic stressors of the riparian ecosystem at LIBI include changes in hydrologic regimes, livestock grazing (upstream), and high concentrations of heavy metals in channel and river bank

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Figure 14. Left bank of the Little Bighorn in 2013 near the middle of the SEI sample reach showing reduced riparian cover and row crop agriculture. See Figure 11 for a view of the right (LIBI side) bank (where much more riparian cover and structure exists).

sediments. Naiman and Decamps (1997) provide an overview of the potential mechanisms behind these simple proxies of river or riparian condition. The SEI protocol does not directly measure the impact of anthropogenic disturbances on streams. Rather, indirect proxies are developed based on the spatial proximity of types of anthropogenic landuse. Metrics are created from these data as weighted averages across all riparian plots, with disturbances closer to the Little Bighorn assumed to be more important (metrics range from 0 for no disturbance to a theoretical maximum of 22 if a disturbance was in the channel at every station). The index of human disturbances of all types combines a proximity weighted average of the complete list of disturbance cataloged in the SEI protocol (channel revetment, pipes, channel straightening, bridges, culverts, buildings, lawns, roads, pastures, orchards, row crops, and miscellaneous "trash" (e.g., car bodies, grocery carts, pavement blocks, and other trash) and transforms the value to vary inversely with disturbance (0 at a maximum disturbance, 1 with no disturbance).

We also develop a riparian vegetation alteration metric that combines extant vegetation cover with the proximity-weighted inverse tally of riverside human activities. The index value decreases with increases in riverside human activities, and increases with increasing riparian woody vegetation complexity and riparian cover density (low values of the index correspond to a higher risk of disturbance at sites given higher anthropogenic presence coupled with low vegetation complexity that might mitigate this disturbance). This index is relevant in riparian settings where a multi-storied riparian corridor (including woody vegetation) and a bankside canopy is the expectation; we feel this is appropriate for the Little Bighorn at LIBI. In contrast, this metric would not be appropriate for a prairie stream lacking naturally occurring woody vegetation on its floodplain.

Finally, we also include the presence of invasive plants as both indirect indicators of human disturbance and measures of direct disturbance. Invasive plants are (usually non-native) species whose introduction causes or is likely to cause economic or ecological harm or harm to human health (Clinton 1999). Invasive taxa in riparian systems are especially important as the connectivity afforded by the river network provides an additional pathway for invasion of riparian vegetation to a broader landscape (Ringold et al. 2008, Merritt and Wohl 2002). SEI data on invasive taxa are very simple and should not replace other efforts to catalog (or manage) this issue. Future work will compare SEI data with more rigorous data sets.

There are no established assessment points or regulatory criteria available for these metrics, and we only make qualitative comparisons to mean values across the ecoregion (using EMAP data). Patterns at LIBI were mixed relative to ecoregion reference site means. There were higher scores (or these disturbance types were more prevalent) for roads and row crops at LIBI than across the ecoregion, but lower scores for all types of agriculture combined (perhaps because of less pasture at LIBI than the typical prairie stream) and revetments, even though the top of the LIBI reach does have some rip rap. However, the index of all human disturbances was lower (suggesting lower overall disturbance) at LIBI than the ecoregion reference mean (0.41 vs. 0.57 (SD=0.01); Table 11). The riparian vegetation alteration metric at LIBI suggests higher disturbance relative to a reference condition. There are no established assessment points or regulatory criteria available for this metric. Given the useful way this metric combines disturbance and factors that might mitigate stress, we compared riparian vegetation alteration at LIBI to assessment points from the distribution of reference sites from across the ecoregion (50^{th} percentile for reference=0.03; 25^{th} percentile non-reference=0.015; note that decreasing values are associated with a declining condition; a reference state is above the 50^{th} percentile and a non-reference is below the 25^{th} percentile; Table 11. The vegetation disturbance metric at LIBI (0.01 in 2009) was in the 8^{th} percentile of the reference distribution, below (or in a non-reference state) the 50th percentile reference assessment point of 0.03.

In general, the results for human disturbance at LIBI are mixed likely due to the very different land use regimes on the left (private) and right (park) banks of the river. The interpretation of this in the context of the ecological integrity of the Little Bighorn at LIBI is complicated. It is possible that the best management practices utilized by the park (and many of the private landowners that surround the park) mitigate riparian disturbance from being a source of local disturbance and reduced ecological condition in the channel.

Invasive Riparian Plants

Three of fifteen targeted invasive taxa were present at sample transects at LIBI: Canada thistle (*Cirsium arvense*), Russian olive (*Elaeagnus angustifolia*), and Salt Cedar (*Tamarisk* spp.) with frequencies ranging from 0.2 to 0.73. While SEI data does not quantify abundance or population size, many patches appeared to be fairly large (Figure 15). Note that SEI invasive plant data should not be considered as rigorous as that generated by focused weed programs that LIBI or other collaborators conduct, especially any effort that generates a complete description of all species in a plot (such that a degree of community invasion could be derived). For example, LIBI staff knows that houndstongue is abundant on the floodplain at LIBI but was not documented by SEI crews given its difficult identification during boat sampling. Importantly, SEI results describe both sides of the river. This is appropriate as the entire floodplain matters to the river. LIBI has actively treated the park side of the floodplain and as of 2009 there were no Russian olive and only trace amounts of salt cedar remaining on the park side (M. Stichmann, pers. comm., 2012). The park is working with local landowners to manage these species across the entire floodplain.

Figure 15. Russian olive (*Elaeagnus angustifolia*) canopy with Canada thistle (*Cirsium arvense*) on the left bank (not park side) of the Little Bighorn at LIBI in 2009.

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There are no established assessment points or regulatory criteria available for these metrics. However, Canada thistle and salt cedar are Priority 2b on the Montana Noxious weed list (MT DOA 2012). These weeds are abundant in Montana and widespread in many counties. Management criteria for these taxa requires eradication (or containment where less abundant) and shall be prioritized by local weed districts (or parks). Russian olive is a regulated plant but not considered noxious. It has the potential to have significant negative impacts and may not be intentionally spread or sold other than as a contaminant in agricultural products. Montana Fish, Wildlife and Parks (MT FWP 2008) states that all of these taxa may render land unfit or greatly limit beneficial uses.

LIBI considers several taxa on the SEI list (taxa noted in Table 10) as special taxa of concern and is managing them as part of an Early Detection Rapid Response (EDRR) strategy. The EDRR strategy means locating a potential invasive plant that is just beginning to invade a particular area and quickly treating any new infestations. However, management priority for these weeds is in uplands (as opposed to floodplain) given the importance of the cultural landscape and proximity to high visitor use areas and road/trails as high vectors for invasion.

We also use a metric of the summed frequency of all invasive taxa we searched for along the LIBI sample reach. Metric values range from a maximum of 17 if all taxa occur in all riparian plots, to 0 if no taxa were found. At LIBI in 2009 this metric was 1.54 (Table 11 and Table 12). There are no established assessment points or regulatory criteria available for this metric. Comparisons to other datasets are also complicated if lists of the target taxa included in this metric differ (as they do across SEI and EMAP). Moreover, one of the most significant limitations of SEI invasive plant data set is that it focuses on a select set of species rather than on the full assemblage. The result is that the focus of the analysis is best placed on the status of a species rather than on the overall invasion status of the riparian community at a reach. We will therefore use this combined metric only in comparisons across time (and only over a period in which the target species list remains the same). Species-level comparisons will still be possible over time and with external data across the Northern Great Plains ecoregions (below).

For comparisons across the ecoregion we focus on Canada thistle, Russian olive, and salt cedar as these taxa were also included at EMAP sites in the ecoregion. Note that EMAP data was collected in 200-2003 and is therefore almost a decade old compared to the SEI data used in this report. Canada thistle occurred (i.e., was present in at least one plot at site) at about 39% of the reference sites in the ecoregion, with an average frequency (i.e., the mean proportion of plots occupied across sites it was present in) of about 0.26 (SD=0.4). Therefore the degree of thistle invasion at LIBI (frequency of 0.73) is higher than at the typical reference site in the ecoregion. Russian olive occurred at about 21% of the reference sites in the ecoregion, with an average frequency of about 0.06 (SD=0.2). Therefore, the degree of Russian olive invasion at LIBI (frequency of 0.53) is higher than at the typical reference site. Finally, salt cedar occurred at about 3% of the reference sites in the ecoregion, with an average frequency of 0.002 (SD=0.01) and the degree of salt cedar invasion at LIBI (frequency of 0.27) is also higher than at the typical reference site in the ecoregion.

<u>Signal to Noise Ratio</u>

The S:N of the human disturbance metrics was generally acceptable within the EMAP program, suggesting that they are estimating conditions in LIBI with acceptable precision.

Table 12. Frequency of 17 target invasive taxa at LIBI during 2009 sample event. Values range from 0 to 1, with 1 describing a species that occurred at all 11 riparian plots. *Taxa are on the LIBI Early Detection Rapid Response list.

Taxa	2009
Spotted knapweed (*Centaurea maculosa*)	0
Oxeye daisy (*Chrysanthemum leucanthemum*)	0
Canada thistle (*Cirsium arvense*)	0.73
Houndstongue (*Cynoglossum officinale*)	0
*Leafy spurge (*Euphorbia esula*)	0
St. Johnswort (*Hypericum perforatum*)	0
Dalmatian toadflax (*Linaria dalmatica*)	0
*Yellow toadflax (*Linaria vulgaris*)	0
Common tansy (*Tanacetum vulgare*)	0
*Orange hawkweed (*Hieracium aurantiacum*)	0
*Meadow hawkweed Complex (*Hieracium pratense*, *H. floribundum*, *H. piloselloides*)	0
Purple loosestrife (*Lythrum salicaria*, *L. virgatum*, and any hybrid crosses)	0
*Tall buttercup (*Ranunculus acris*)	0
Tansy ragwort (*Senecio jacobea*)	0
Russian olive (*Elaeagnus angustifolia*)	0.55
Salt Cedar (*Tamarisk* spp.)	0.27
Japanese knotweed (*Polygonium cuspidatum*)	0
Index for all taxa (ip_score)	1.54

S:N for the agriculture proximity metric was a bit low. The vegetation disturbance metric was a very precise measure, with a S:N ratio of 16.6. S:N was not calculated for invasive plant metrics. Ringold et al. (2008) describe the various issues with the quality of these data, and as we note above, they should not replace more focused efforts.

Hydrology: Stream Flow

The hydrologic regime, or the amount and timing of stream flow, is one of the most important aspects of stream habitat and a key long-term monitoring response within the SEI protocol. We used data available from the nearby USGS gauge near Hardin to develop detailed hydrographs for the 2007 to 2010 water years and present trend models of discharge over a 30-year period of record (given in the trend analysis section above). We also conducted a flood frequency analysis of the period of record (note we use 1953 to 2013) from the Hardin gauge to determine the magnitude and recurrence interval of annual expected flood peaks and better place SEI monitoring in context. Because the State of Montana does not have numeric streamflow criteria, our interpretation of the hydrologic regime during SEI monitoring is largely qualitative.

Hydrographs from the USGS gauge for the 2007-2010 water years are shown in Figure 16. These plots show daily discharge and its mean for a 30-year period of record (1978-2011). They also include the median total discharge for the water year and the historic period of record. Table 13 presents the total, minimum and maximum flow along with the date of maximum flow for these same time periods. Table 14 shows the results from the HEC-SSP model of flood frequency for the Hardin gauge.

Given the distance between LIBI and the Hardin gauge (more than 30 river miles) we first compared stream flow at the two

Table 13. Select stream flow statistics from the Hardin USGS station on the Little Bighorn River upstream of LIBI. All discharge results are in cubic feet per second (cfs).

Water Year	Total Discharge	Minimum Discharge	Peak Discharge	Date of Maximum Discharge	Median Discharge	Standard Deviation in Discharge
2008	109,143	70	2,270	May 26	162	361
2009	94,298	70	1,130	June 8	170	222
2010	95,390	70	1,650	June 13	155	297
Historic (1980-2010)	99,384	40.5	2,180	May 23	163	310

Table 14. Flood frequency analysis for the extended Hardin USGS gauge period of record (1953 to 2013). Two year and ten year return intervals are highlighted in red. All discharge results are in cubic feet per second (cfs).

Computed Flow	Percent Chance Exceedance	Return Period (yrs.)	Confidence Limit (0.05)	Confidence Limit (0.95)
31088.60	0.20	500.00	53154.50	20765.50
20785.60	0.50	200.00	33237.10	14571.90
15159.80	1.00	100.00	23023.40	11028.20
10921.10	2.00	50.00	15741.40	8245.30
6898.70	5.00	20.00	9273.70	5467.70
4736.50	10.00	10.00	6044.10	3886.60
3124.60	20.00	5.00	3800.20	2639.00
1581.90	50.00	2.00	1851.50	1345.30
922.40	80.00	1.25	1095.50	754.00
732.70	90.00	1.11	883.80	583.50
621.00	95.00	1.05	759.10	484.30
481.20	99.00	1.01	602.20	362.40

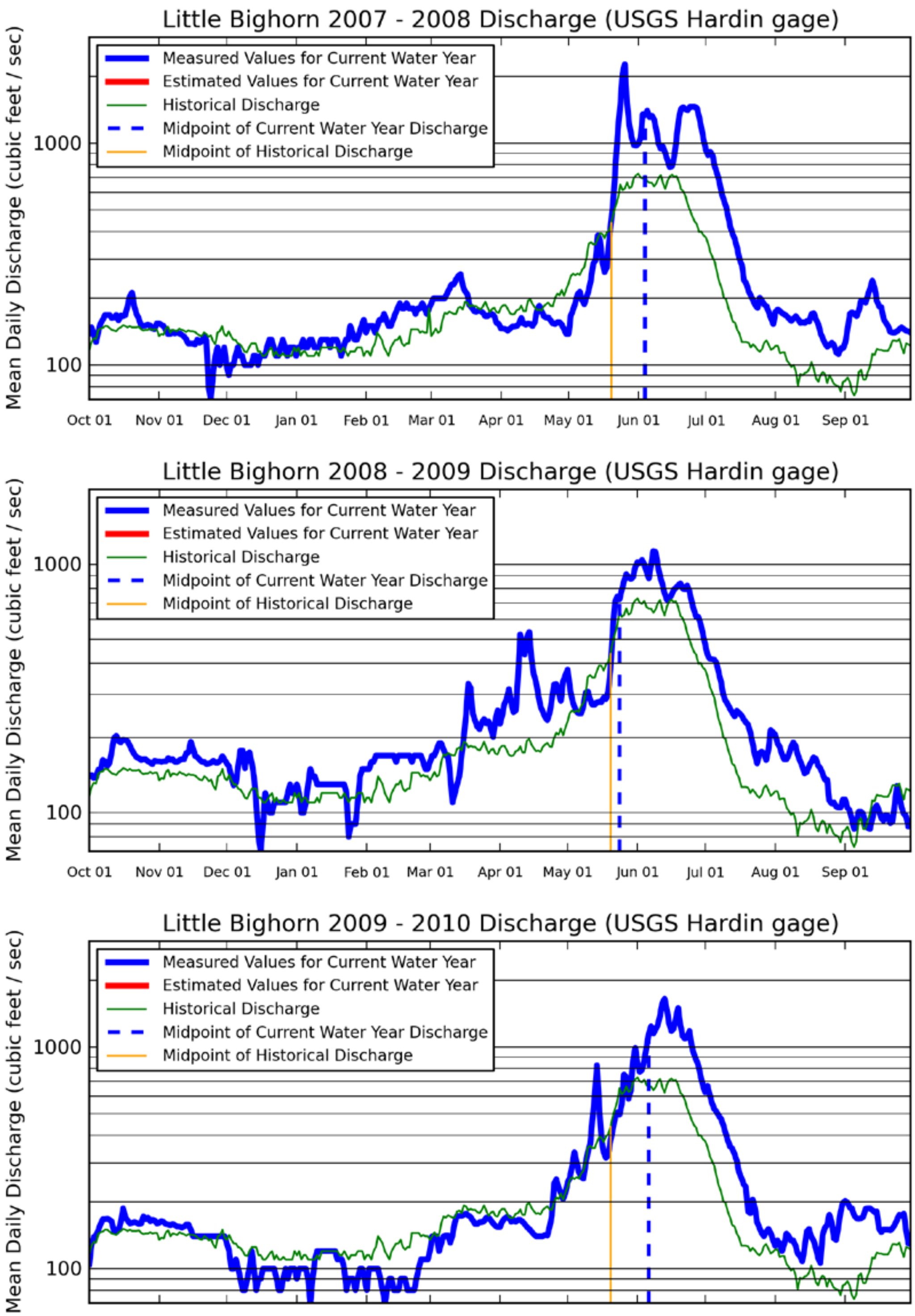


Figure 16. Hydrographs for 2007-2010 water years at the Little Bighorn River Hardin USGS gauge (station 629400). Figures include current water years (heavy blue or red lines), 30-year normal (mean daily values) for 1980-2010 (light green lines) and the midpoint of current and historical discharge. Additional statistics are given in Table 11. Graphics were produced in the Climate Data Summarizer, version 3.2 courtesy of Mike Tercek.

locations using USGS and NPS data from the WRD gauge at LIBI (we do not use these data to actually describe hydrology at LIBI as NPS WRD considers them provisional, but they are adequate for this comparison). Figure 17 shows a simple linear model between the two time series using daily mean discharge on days the gauges ran concurrently. The fit between the two data sets is strong, with an r2 of 0.9. Interestingly, discharge diverges more as flow increases, perhaps reflecting more localized effects of debris jams or the tendency for high flows to be estimated. We interpret these results as suggesting it is generally acceptable to use the Hardin gauge for long-term trend analyses of discharge on the Little Bighorn at LIBI.

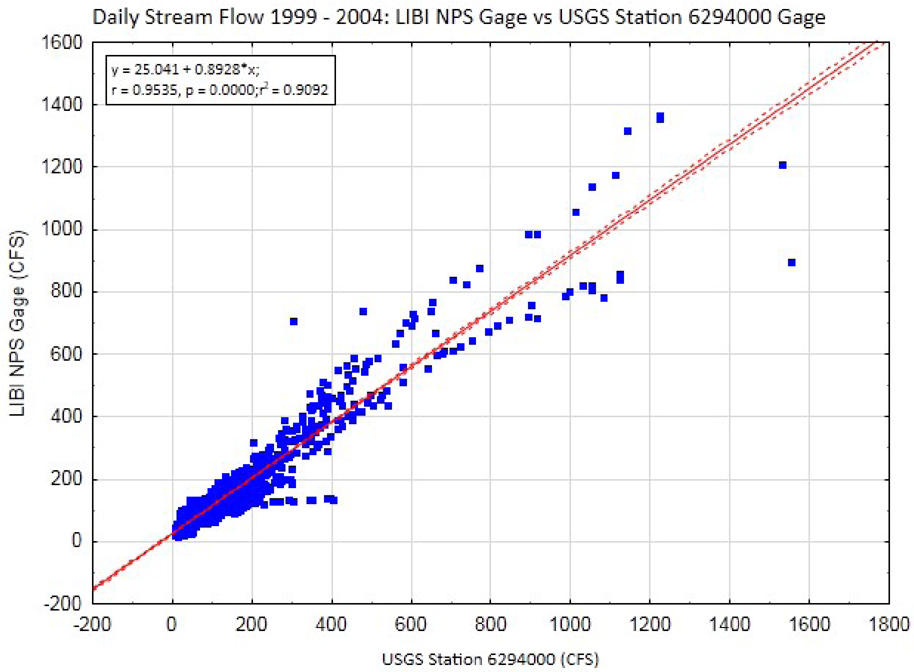


Figure 17. Linear model comparing daily mean stream discharge at the NPS WRD gauge in LIBI with the USGS gauge in Hardin from 1999-2004.

Qualitative comparisons of discharge in the 2008 to 2010 water years to the period of record suggest SEI monitoring to date has occurred under somewhat mixed hydrologic conditions, with 2008 a wet year (above the two-year flood recurrence interval), but 2009 and 2010 slightly dryer. Seasonal patterns were fairly typical for larger rivers on the eastern plains of Montana with a discharge peak in May to June driven by snowmelt and spring rains. Streamflow decreased rapidly through July and was lowest in August and September due to low precipitation rates and high rates of evapotranspiration. During summer months, water also is diverted from the river for irrigation. The 2008 water year was more variable than the historic average with higher peak flows and more variation in flow. During the 2009 and 2010 water years, maximum flow occurred later in the year and the midpoint of flows also shifted to later in the year. Minimum flows were also higher in these three years perhaps due to apparent dewatering periods in the early 1960s and 2000s that lowered the historic mean minimum flow. When discharge data from the Hardin gauge are adjusted for seasonal patterns and tested for longer-term trends (see above, and Figure 10) there was a marginal (p=0.10) negative trend of -0.71 cfs/year. The slightly dryer years (in terms of total streamflow and median flows) of 2008-2010 fit this pattern.

Biology

Summary

In general, patterns across macroinvertebrate and diatom bioassessment metrics at LIBI were complex in 2007 and 2009, with some indicating a reference and some a non-reference condition. Table 15 presents a simple summary with more detailed results below.

A weight of evidence approach in interpreting the biological metrics at LIBI suggests that the Little Bighorn had somewhat reduced overall ecological integrity in 2007 and 2009, with a biological response to fine sediments and potentially nutrients. State guidance for resolving mismatched bioassessment results is conservative and MT DEQ would likely conclude the benthos and diatom assemblages were not in a reference state at LIBI. However, there is some concern by MT DEQ and other partners that the current bioassessment metrics for the eastern plains of Montana are not entirely useful and there is ongoing research to improve these. Furthermore, the biological response seen at LIBI generally does not match our assessment of SEI (and USGS) chemistry and habitat data although we believe there is a methodological challenge or incongruence in how habitat and diatom data are collected and analyzed. We currently lack data to assess trends in biological response.

Biological Metrics and Assessment Points

The number and quality of biological metrics and their associated assessment points have been rapidly increasing over the last decade nationwide and in particular in Montana through work by the State of Montana and its partners. We chose biological metrics largely following MT DEQ guidance (Appendix B and Schweiger et al (In Review) provide an overview of the biological metrics presented here). provide an overview of the biological metrics presented here). Assessment points are primarily those developed by MT DEQ but we do include some from other agencies or that are found in the literature. Finally, we derive ecoregion assessment points for select macroinvertebrate metrics (we will do this for diatom metrics in future reports).

Using biological data is only one component of water quality assessment as practiced by MT DEQ (MT DEQ 2012a, b, d). Depending on the availability and rigor of other data (i.e., chemistry), biological response cannot be used alone by MT DEQ for beneficial use determination. However, because NPS is not a regulatory agency, we are freer to stress biological condition in our informal assessment of the status and trend in the condition of the Little Bighorn at LIBI.

Quality Assurance and Quality Control

Signal to noise values are available from EMAP for a few macroinvertebrate metrics, but not for diatom metrics. Therefore, QAQC for benthos includes both field and lab procedures and our qualified application of the S:N results from EMAP, while for diatoms we must rely only on field and lab procedures alone. We report EMAP S:N for these benthos metrics in Table 12 and discuss them in relevant sections below. Appendix E presents mode details on ROMN QAQC procedures.

Macroinvertebrates

We present results for macroinvertebrates in Table 16. Our interpretation of biological condition at LIBI emphasizes the Montana Plains Multimetric Index (MMI; Jessup et al. 2006) and two RIVPACS metrics (O:E and Bray Curtis (BC); Hawkins 2005, Van Sickle 2008). These models were used by the State of Montana through 2011. We also include

Table 15. Summary condition table excerpt for select biological metrics at LIBI in 2007 and 2009. We include example vital signs and indicators, a brief description of results and patterns, and symbolize the status, trend, and our confidence in those summaries. See the Executive Summary for the complete Summary Condition Table.

Vital Sign (Example Indicators)	Summary	Symbol
Biological communities, macroinvertebrates (MMI and RIVPACS metrics)	Patterns across macroinvertebrate metrics were complex. The weight of evidence suggests that there was a non-reference community present. Littoral fine sediment may be the primary cause behind a degraded condition but it is not clear if the level of fine sediments at LIBI are natural or are caused by anthropogenic activities in the watershed. We lack data to assess trends. We have lower confidence in our assessment of benthos communities at LIBI due to possible imprecision in some macroinvertebrate models developed for warm water or plains rivers like the Little Bighorn.	
Biological communities, diatoms (increaser metrics, MMI)	Like macroinvertebrates, most diatom metrics suggested a degraded conditions in the river, especially in response to sediment and nutrients. Diatoms are the base of the food chain and the lack of an intact diatom community may be one of the reasons why we also see lower quality macroinvertebrate assemblages. We lack data to assess trends. We have lower confidence in our assessment of benthos communities at LIBI due to possible imprecision in some diatom models developed for warm water or plains rivers like the Little Bighorn.	
Aquatic invasives (presence)	No aquatic invasive species were found, although the New Zealand mudsnail is in the Bighorn River watershed and likely on the move. SEI monitoring will watch closely for these and other invasive species over the coming years. We have medium confidence in our assessment of aquatic invasives at LIBI.	

Table 16. Summary of core macroinvertebrate metrics for the Little Bighorn River in Little Bighorn Battlefield National Monument, 2007-2009. Assessment points are derived from various sources and are for reference or non-reference condition classes with the direction of the inequality indicating whether the state is above or below a value. Select ecoregion assessment points are given within parentheses. Metric values in **bold red** are in non-reference. Metric values in **bold green** are in reference. Metric values in **bold** are either intermediate or non-reference (depending on the existence of a non-reference assessment point). For additional clarifications on Table content see Notes below.

Metric	2007	2009	Reference Assessment Point	Intermediate Assessment Point(s)	Non-reference Assessment Point	EMAP Signal:Noise[x]
Current MT DEQ Metrics						
Plains Multimetric Index (MMI)	**46**	**58**	>37[1] (>52.2)[2a]	--	(<42.5)[2a]	2.95
RIVPACS O:E (P>0.5)	**0.27**	**0.68**	>.81 (>0.96)[2a]	--	(<0.82)[2a]	1.44
RIVPACS O:E (P>0.0)	1	1.2	--	--	--	--
RIVPACS Bray Curtis dissimilarity (P>0.5)	**0.68**	**0.35**	(<0.28)[2b]	--	(>0.29)[2b]	--
RIVPACS Bray Curtis dissimilarity (P>0.0)	0.78	1	--	--	--	--
Classic or Disturbance Specific Metrics						
Plains Multimetric Index (classic)	**70**	**90**	>75[3]	75-25[3]	<25[3]	--
Karr Benthic Index of Biotic Integrity	**40**	**60**	>46[4]	44-38, 36-28, 26-18[4]	<16[4]	--
Hilsenhoff Biotic Index (Nutrients)	**5**	**5**	<3[5]	--	>4[5]	1.3
Fine Sediment Biotic Index	**2.8**	**4.1**	>8[6]	7-6, 5-4[6]	<3[6]	--
Temperature Index	18.2	18.0	--	--	--	--
Metal Tolerance Index	**4.71**	**4.09**	<4[7]	5-8[7]	>8.9[7]	--
Current MMI Component Metrics						
EPT Taxa Richness	8	15	--	--	--	2.02
Percent Tanypodinae	0[xx]	1.7	--	--	--	--
Percent Orthocladiinae of Chironomidae	0[xx]	41	--	--	--	--
Predator Taxa Richness	6	8	--	--	--	0.83
Percent Filterers and Collectors	96	82	--	--	--	0.51

Notes

[1] MMI and O:E (p> 0.5) metrics and their assessment points were used by MT DEQ through 2011 (MT DEQ 2012d); values above or equal to a criterion are in reference (or if assessed by MT DEQ, "Not Impaired" and support designated use(s)), values less than a criterion are in non-reference (or "Impaired" and do not support designated use(s)).

[2a] MMI and O:E (p>0.5) ecoregion assessment points generated from reference sites in the Northwestern Great Plains ecoregion; decreasing values are associated with a declining condition at the >50th/<25th percentile values for reference/non-reference, respectively. These assessment points are not used by MT DEQ.

[2b] Bray Curtis ecoregion assessment points generated from reference sites in the Northwestern Great Plains ecoregion; increasing value is associated with a declining condition and assessment points in ecoregion reference site distribution are at the <50th/>75th percentile values for reference/non-reference, respectively. Note that MT DEQ does not use the p>0.0 version of this metric (see text) and these assessment points are not used by MT DEQ.

[3] Plains MMI was used by MT DEQ prior to the current MMI model; (Bukantis 1998, MT DEQ 2005); values above or equal to 75 were in reference (or if assessed by MT DEQ, were in "Full support–standards not violated,"); values between 25 and 75 are intermediate (or if assessed by MT DEQ, were in "Partial support–moderate impairment–standards violated"); values less than 25 are in non-reference (or if assessed by MT DEQ indicate "Non-support–severe impairment-standards violated").

[4] Karr Benthic Index of Biotic Integrity has never been used by MT DEQ; classes are described by (Karr 1998) as Excellent (we use this as reference), with intermediate classes Good, Fair, Poor, and finally Very Poor (we used this as non-reference).

[5] Hilsenhoff Biotic Index (Hilsenhoff 1988) can be used in support of other nutrient data by MT DEQ (Suplee and Sada de Suplee 2011); values less than 3.0 are in reference (or if assessed by MT DEQ, "full support of aquatic life"), values greater than 4.0 are in non-reference (or if assessed by MT DEQ, "impairment of aquatic life").

[6] Fine Sediment Biotic Index (Relyea et al. 2000) has never been used by MT DEQ; values above 8 are fine sediment intolerant (we use this as reference), 7-6 are moderately intolerant to fine sediment, 5-4 are moderately tolerant to fine sediment and <3 fine sediment tolerant (we use this as non-reference).

[7] Metal Tolerance Index (McGuire 1987, 1989; Ingman and Kerr 1989) is specific to the Clark Fork and are not used by MT DEQ on the Little Bighorn (we apply these to LIBI with caution); values less than 4 are in reference (or if assessed by MT DEQ, indicate "metals intolerance"); values between 5 and 8 are intermediate, values greater than 8.9 are in non-reference (or if assessed by MT DEQ indicate "metals tolerance").

[x] S:N is the ratio of information to noise in a metric. Higher S:N values suggest the metric had more signal or true information than variation due to crews, season and other sources (see text and Kaufmann et al. 1999, Stoddard et al. 2005). S:N source data are from EMAP sites in a broader bioregion ("Plains").

[xx] Midges were not identified to at least subfamily in 2007. However, because the two component metrics based on midges respond in opposite ways to increased stress we elected to retain the overall MMI in 2007.

a suite of classic and disturbance-specific metrics that we feel have interpretative value and/or connect SEI results to previous monitoring at or near GRKO and across the state. Finally, we include interpretation of select taxa using demonstrated associations between assemblage components, habitat and water quality variables from the literature and professional judgment. We feel narratives of the presence/absence or abundance of specific invertebrate taxa lend a more intuitive nature to SEI results (even though many of the species will not be familiar to the casual reader).

Current MT DEQ Metrics

The MMI and RIVPACS metrics and criteria as used by MT DEQ (through 2011) suggest that during base flow in 2007 and 2009 the Little Bighorn at LIBI was in a mixed condition. Results varied across metric and years, indicating there was a meaningful amount of variation in biological response and/or potential shortcomings or inconsistencies in the application of the models (see below). Similar mixed patterns were seen when using the (slightly more conservative) ecoregion reference assessment points.

Specifically, the values for the MMI were above the MT DEQ criterion of 37 in both years. This indicates that through 2011 MT DEQ would likely have considered the life histories, stressor tolerances and community composition attributes as summarized in the MMI characteristic of a reference condition macroinvertebrate assemblage. The Northwestern Great Plains ecoregion reference assessment point for the MMI was more conservative (at around 52) and the MMI at LIBI was only in reference relative to this value in 2009 (but close in 2007). The MT DEQ value was estimated for all plains streams in the state and reflects a lower quality reference state. The ratio of observed to expected taxa (O:E) from the RIVPACS model was well below (or in non-reference) the MT DEQ criterion (0.8) in 2007 and closer but still not in the reference range in 2009. In both years the O:E score was also below the ecoregion reference assessment point. This suggests that a sizable proportion of the species observed at LIBI were not characteristic of or those expected in a reference stream in Montana. In a sense there may be “missing” species expected in higher quality rivers.

The Bray Curtis (BC) dissimilarity metric index has some advantages over O:E and MT DEQ recommends using both indices (MT DEQ 2012d). The BC index can facilitate determining if expected reference taxa are being replaced by more tolerant taxa (i.e., indicative of a non-reference state) in sites transitional between reference and non-reference conditions. The BC index is most useful when a high (i.e., good) O:E score is generated from a known or suspected non-reference stream. O:E can be relatively insensitive to stress-induced shifts in taxonomic composition that have little net effect on the number of reference-site taxa (Hawkins et al. 2000, Davies and Jackson 2006).

Patterns in BC values at LIBI largely agreed with O:E results when (following MT DEQ guidance) the taxa included were restricted to those that were more common (with a probability of capture greater than 0.5), with fairly strong indication of dissimilarity between a reference assemblage and what was actually observed. In 2009, the difference was smaller, suggesting that the community was more intact (this increase in condition was also seen in the MMI). If rarer taxa (with a probability of capture less than 0.5) were included, the BC value increased, further suggesting that (rare) species indicative of a reference state were less likely to occur at LIBI. The O:E metric, when also calculated using rare species, increased —but this suggests the opposite pattern as the BC metric or that more reference taxa than expected were actually observed. The choice to include rare species or not in bioassessment is a much debated subject, with no clear direction as to what is the right approach (Cao et al. 1998, Clarke and Murphy 2006, Van Sickle et al. 2007, but see Ostermiller and Hawkins 2004). Some taxa that are more sensitive to stress (or occur in reference sites) are naturally less widespread and thus tend to have considerably lower average site-specific expected probabilities. The use of higher probability of capture assessment points (i.e., greater than 0.5) can exclude these more sensitive taxa and may lead to a lack of sensitivity in the estimation of condition. More data and analysis will be needed to resolve this potentially complex result. However, while there are no State of Montana criteria for the BC index, LIBI BC scores were well above (or in a non-reference condition) the ecoregion reference assessment point. This supports the general conclusion from the MMI and O:E metrics that the community of macroinvertebrates at LIBI was of mixed or generally lower quality.

Signal to Noise Ratio
The S:N of the MMI metric was acceptable within the EMAP program, with relatively high values suggesting that the metric may be estimating conditions in LIBI with acceptable precision. The S:N value for the O:E metric; however, was not as high.

<u>Classic and Disturbance Specific Metrics</u>
Although the classic and disturbance specific macroinvertebrate metrics are not currently used by MT DEQ for regulatory decisions and the current MMI out-performed a suite of classic indices (Jessup et al. 2006) we feel they still have value in assisting in the general interpretation of the condition of the macroinvertebrate assemblage at LIBI. They may also help resolve the mixed results from the MMI and RIVPACS metrics. However, the following results and interpretation should be used with caution.

The Plains Multimetric Index (Bukantis 1998, MT DEQ 2005) in 2009 and 2007 was within the reference region or near the upper end of the intermediate class (respectively). This is similar to the current MMI. The Karr Benthic Index of Biotic Integrity (Karr 1998) in 2009 and 2007 was also within the "excellent" or "good" class (respectively). The Karr metric was originally calibrated for the Pacific Northwest, so it may not be well suited for the disturbance regime and river type at LIBI. Nevertheless, it has been successfully used across the West and we include it here for comparative purposes.

The Hilsenhoff Biotic Index (HBI; Hilsenhoff 1987) is an index of stream nutrient concentration based on tolerance values of a large number of macroinvertebrate taxa to organic pollution (Barbour et al. 1999). HBI is calculated as a weighted average tolerance value of all individuals in a sample. Higher index values indicate increasing tolerance to nutrient concentration. It has a sufficiently predictive response to nutrient gradients in Montana's mountain streams that MT DEQ uses it as a secondary response variable to help assess nutrient impacts (MT DEQ 2011a). Research is ongoing to apply this tool eastern Montana streams like the Little Bighorn and we use it at LIBI with caution.

At LIBI, the HBI was above but close to its reference assessment point suggesting a limited biological response to elevated nutrients (a similar limited response is seen in the diatom community, see below). However, SEI water chemistry monitoring do not indicate that N and P concentrations were above MT DEQ (2012) nutrient criteria (Table 6) and we suspect that this small nutrient signal is just imprecision in the metric. However, nutrient pollution can be a widespread and significant stressor in rivers and watersheds like the Little Bighorn and we will continue to evaluate this response in future work.

The Fine Sediment Biotic Index (FSBI) metric is another tolerance based index that describes the response within the benthic community to fine sediment (Relyea et al. 2000). Lower scores indicate a community with more taxa capable of persisting in systems with higher levels of fines. It was developed for the north western U.S. from 561 streams. While potentially more relevant to smaller mountain streams the model does include rivers from ecoregions similar to LIBI and many taxa included in the effort occur in LIBI samples. FSBI results at LIBI were below the non-reference assessment point in 2007 and the second to lowest class (out of four) in 2009 indicating that the benthos assemblage consisted of taxa that were moderately to very tolerant of fine sediment. At least in 2007, this does not match SEI habitat data for small sediment (see Table 11), indicating that either the FSBI is not well suited to LIBI or that there was perhaps a temporal (habitat data are from 2009) or spatial (2007 benthos data came from an ad hoc set of subsample locations) disconnect in the two types of data. However, as the response of the macroinvertebrate community to fine sediment is generally similar to diatom metrics for sediment (see below) the weight of evidence does suggest a biological response to fine sediments at LIBI. Fine sediments can limit access for some taxa to key habitat and can have a dramatic impact on the overall macroinvertebrate community and stream food web. This result will need close scrutiny over the coming years.

The Temperature Index results are slightly below the mean August temperature at LIBI of around 22°C from SEI and USGS temperature data (see Table 7, Figure 9 and Figure 10). There are no assessment points for the Temperature Index and MT DEQ does not use it in any formal way. However, it supports direct measures of temperature and extrapolates this across a broader spatial and temporal scale via the preferred temperatures of macroinvertebrates. Previous monitoring in and near the Little Bighorn (Bollman and Teply 2006) has used this metric as evidence of possible dewatering or thermal stress (metric values were above measured or expected temperatures). There are periods of dewatering on the Little Bighorn in the long-term hydrology data set, but no evidence of this in the last decade or so.

The Metal Tolerance Index (MTI) metric quantifies changes in community composition attributable to metals pollution. The format and calculation is similar to the HBI (see above), with tolerance values assigned to each taxon based on sensitivity to metals. The scale of the index is 0 to 10 with higher values indicating communities more tolerant of metals pollution. McGuire (2010) suggests that MTI values for communities dominated by species intolerant of metals are less than 4 while values for communities composed of only the most metals-tolerant species approach 10. Metals tolerance values for most taxa were developed from (Ingman and Kerr, 1989) and (McGuire, 1987 and 1989). MTI values in both years at LIBI indicated little to no or only moderate metal issues. This generally matches the results from diatom metal metrics (see below). When coupled with the lack of metal signal in SEI sediment chemistry data (Table 6), we are confident that there are few if any metal issues at LIBI.

Component MMI Metrics and Interpretation of Taxonomic Composition

The following section briefly summarizes select patterns in the five component metrics (EPT taxa richness, percent Tanypodinae, percent Orthocladiinae of Chironomidae, predator taxa richness, and percent filterers and collectors) that comprise the current Plains MMI. We also include discussion of a few specific taxa of note (i.e., Bollman and Bowman 2007). A complete taxa list with counts and relative abundance values is given in Appendix D.

Using a consistent Operational Taxonomic Unit (OTU) level to define unique taxa, we collected a total of 69 taxa across the two sample events. The abundance of organisms was high in each sample and we reached the maximum pick size of 600 in 2007 and nearly so in 2009. In general, the community composition was typical for the recent Little Bighorn River (Bramblett et al. 2003), with mayflies (Ephemeroptera), caddisflies (Trichopetera), and true flies (Diptera) major components of the assemblage. Stoneflies (Plecoptera) and dragonflies (Odonata) had more restricted distributions.

The taxon with highest total count and relative abundance across both LIBI samples was the caddisfly genus *Cheumatopsyche* spp., with a mean relative abundance around 43% in 2007. In 2009, two mayfly genera (*Tricorythodes* spp. at 19% and *Fallceon* spp. at 17%) were also relatively common (Figure 18). The higher abundances of these three taxa were likely a large part of the very high (96% and 82 %) values of the percent filterers and collectors component MMI metric that is likely the primary driver of the reduced MMI. The percent of a sample composed of taxa that filter food from the water column tends to increase with increasing anthropogenic stress in eastern Montana plains streams. Specialized feeders, such as predators, scrapers, piercers,

IMAGE COURTESY OF BOB NEWELL VIA THE MONTANA NATURAL HERITAGE PROGRAM (MT NHP 2012A).

Figure 18. Dissecting scope view of a *Tricorythodes* spp. mayfly, common in the Little Bighorn at LIBI.

and shredders, are more sensitive and are thought to be better represented in higher condition streams. Generalists, such as collectors and filterers, have a broader range of acceptable food materials than specialists (Cummins and Klug 1979), and thus are more tolerant to pollution that might alter availability of certain foods. It may also suggest that the food resource in the river or on substrates was more detritus and suspended solids than attached algae. Interestingly, *Cheumatopsyche* spp. often are also associated with stony substrates as seen in many places in the thalweg of the Little Bighorn at LIBI.

The richness of EPT (Ephemeroptera, Trichoptera, and Plecoptera) taxa is generally sensitive to pollution (Barbour et al. 1999), and this component of the assemblage tends to become less specious as stresses increase. In 2007, EPT richness was only 8 (out of 33 taxa total or 24%) and in 2009 it was 15 (out of 50 or 30%). Moreover, there were no Plecoptera (stoneflies) in either collection.

While in most contexts, many midges are tolerant of stress, certain taxa in the subfamily Tanypodinae within the Plains appear to be sensitive to stress. In contrast, relatively tolerant taxa in the Orthocladiinae increase as a percentage of all Chironomidae. Unfortunately, midges in the 2007 LIBI sample were mistakenly not identified past family. Because the two component metrics of the overall MMI that depend upon midges being identified to at least subfamily (genus is preferred) respond in opposite ways to increased stress we elected to retain the overall MMI in 2007 (this error is another reason to include multiple metrics such as the classic and disturbance specific metrics that are not dependent on this level of identification). In 2009, the percent Tanypodinae was only 1.7 while the percent Orthocladiinae of Chironomidae was 41, likely two additional important components of the relatively low MMI in 2009. Finally, the percentage of the LIBI assemblage that consisted of predaceous taxa was somewhat marginal at 6-8%. Predaceous taxa are more common in sites with less stress and more intact aquatic insect food webs.

Finally, as noted above, there were also several taxa in the LIBI samples that had low probabilities of detection. These taxa were included in the RIVPACS model results that suggested that the assemblage was of higher quality. Examples include the clubtail dragonfly family Gomphidae and the moth genus Petrophila, both of which have low tolerance to disturbance. Several Gomphidae are species of concern in eastern Montana (MT NHP 2012b). This suggests that species level identification may be useful for this group at LIBI in the future.

Signal to Noise Ratio
The S:N of the component metrics within the MMI were mixed within the EMAP program, with relatively high values for EPT richness, but lower values for predator taxa richness and percent filterers and collectors. These likely reflect the difficulty in identifying these groups and suggest that the application of the MT DEQ MMI to LIBI should be done with some caution.

Periphyton (Diatoms)
We present results for diatoms in Table 17. Our interpretation of biological condition using diatoms at LIBI emphasizes the Warm Water bioregion sediment and nutrient increaser metrics developed by Teply (2010a, b; MT DEQ, 2011b) and currently used by the State. We do present results for historic diatom metrics (Bahls 1993) including a MMI and its component metrics. Finally, we include select interpretation of specific taxa using demonstrated associations between assemblage components, habitat and water quality variables from the literature and professional judgment. These narratives of the presence/absence and abundance of

Table 17. Summary of core diatom metrics for the Little Bighorn River in Little Bighorn Battlefield National Monument, 2007-2009. Assessment points are derived from various sources and are for reference or non-reference condition classes with the direction of the inequality indicating whether the state is above or below a value. Metric values in **bold red** are in non-reference. Metric values in **bold green** are in reference. Metric values in **bold** are either intermediate or non-reference (depending on the existence of a non-reference assessment point). For additional clarifications on Table content see Notes below.

Metric	2007	2009	Reference Assessment Point	Intermediate Assessment Point(s)	Non-reference Assessment Point
Current Disturbance Specific Metrics					
Sediment Increasers, Warm Water (RA, prob.) [1]	**25.6 (65.6)**	**56.8 (95)**	<17.92 (51)	--	--
Nutrient Increasers, Warm Water (RA, prob.)[1]	**3.9 (28.2)**	**13.8 (57.1)**	<11.21 (51)		
Classic or Disturbance Specific Metrics					
Montana Diatom Multimetric Index[2]	**4**	**4**	≥4	2-3,1-2	<1
Classic MMI Component Metrics					
Shannon Diversity[3]	**4.5**	**4.4**	>2.5	2.5-1.75, 1.7-1	<1
Siltation Index[3]	**36.7**	**29.7**	<20	20-39, 40-60	>60
Pollution Index[3]	**2.27**	**2.51**	>2.5	2.5-2, 2-1.5	<1.5
Disturbance Index[3]	**3**	**8**	<25	25-50, 50-75	>75

Notes

[1] Criteria are currently used by MT DEQ (Teply 2010a, b). The relative abundance (RA) at the 51% level is defined by DEQ as impairment.

[2] Assessment points were historically used by MT DEQ (Bahls 1993); metric values=4 have excellent biological integrity and no overall impairment, metric values between 2 and 3 have good biological integrity and minor overall impairment, metric values between 1 and 2 have fair biological integrity and moderate overall impairment, metric values=1 have poor biological integrity and severe overall impairment.

[3] Assessment points were historically used by MT DEQ (Bahls 1993); values above the first number have no stress/siltation/pollution/ disturbance and "Excellent" biological integrity, "None" impairment, or "Full support" for designated uses; in the second range have minor stress/siltation/pollution/disturbance and "Good" biological integrity, "Minor" impairment and "Partial support" for designated uses; in the third range have moderate stress/siltation/pollution/disturbance and "Fair" biological integrity, "Moderate" impairment and partial support of designated uses; and below the fourth number have severe stress/siltation/pollution/disturbance and "Poor" biological integrity, "Severe" impairment or stress and "Non-support" for designated uses.

specific diatom taxa may lend an intuitive nature to SEI results (even though many of the species will not be familiar to the casual reader).

Northwestern Great Plains Ecoregion Warm Water Sediment and Nutrient Increasers

The Northwestern Great Plains sediment and nutrient increaser models summarize the relative abundance of diatom taxa that, as a group, exist in detectable amounts and demonstrate a meaningful, measurable, and significant response to sediment or nutrients. We found 6 and 8 (2007 and 2009, respectively) sediment increaser taxa, representing a relative abundance (RA) in the two samples of around 26% and 57%. There were 4 and 7 species on the nutrient increaser list in the two samples representing a RA of around 4% and 14%. For sediment, the abundances suggest that the Little Bighorn and LIBI had about a 66% and 95% probability of being impaired due to sediment in 2007 and 2009, respectively. For nutrients, the abundance of increasers suggests that there was about a 28% and 57% probability of being impaired due to nutrients. These probabilities exceed the State of Montana criterion in both sampling events for sediments and in 2009 for nutrients, suggesting that LIBI may have had a meaningful biological response to sediment and depending on year, nutrients.

Patterns in diatom sediment metrics generally match the sediment response seen in macroinvertebrate metrics (Table 16). For nutrients, diatom results suggest a variable response that also generally matches the more muted nutrient signal seen in the macroinvertebrate community and in the water chemistry data (Table 6). The sediment response also is similar to diatom metric data presented by Bahls (2004) for the Bighorn River (below the confluence with the Little Bighorn) near Hardin where there was also a high probability of sediment impairment. However, we did not see a marked sediment issue within the habitat data. We believe this may reflect a methodological incongruence in how habitat and periphyton data are collected and analyzed. Periphyton data are only collected from the littoral areas of the river as it is unsafe (or impossible) to sample deep water habitat. We include substrate data from the thalweg or deep water in our habitat metrics as these methods are safe to implement and this is appropriate for rivers like the Little Bighorn where there can be a meaningful amount of larger substrates in the middle of the channel. Had we constructed LIBI habitat data based sediment metrics using only littoral data, we would have seen higher cover of fine sediments (providing a better fit to the sediment increaser metric). So, at the whole-river scale, there are more large sediments in the system, but when restricted to the shoreline, there are possible excessive fines that drive the diatom increaser response.

Comparison to Northwestern Great Plains Ecoregion Assessment points (TBD)

These comparisons will be done in a future iteration of this report.

Classic and Disturbance Specific Metrics

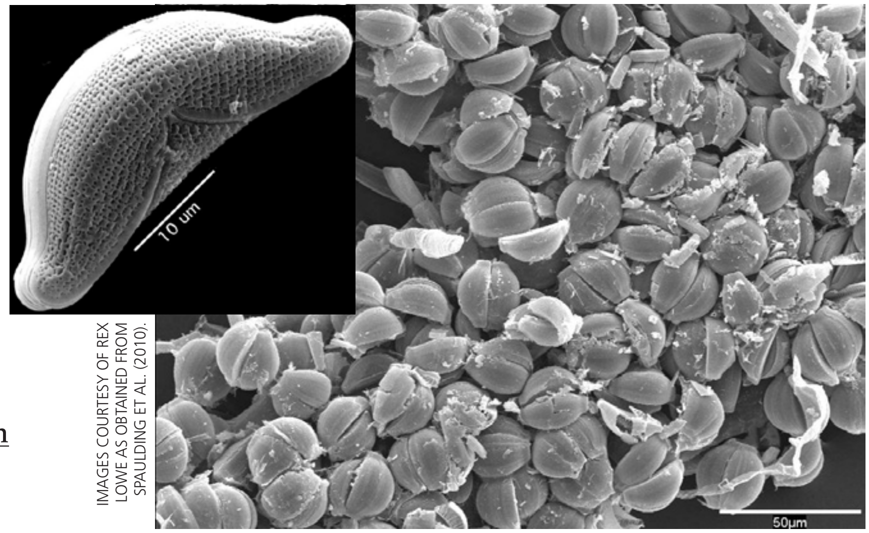
Bahls (1993) developed diatom metrics that were used by the State of Montana in support of monitoring and assessment for nearly a decade, as a diagnostic tool. However, Teply and Bahls (2005) show that these metrics have relatively low capacity to discriminate impairment. Therefore, we use these results only in a general way to help interpret the composition and condition of the diatom community at LIBI.

There were no exceedances of the assessment points for any of these metrics during either sample event at LIBI. While some metrics scores fell within intermediate classes of impairment, most were actually well within the highest quality range. Shannon's diversity was well above the reference assessment point of 2.5, suggesting that the diatom community included a large number of species with generally equitable distributions. This implies that the species replacement seen in the increaser metrics (i.e., more sediment-tolerant species) may not have adversely affected overall diversity. The siltation index was above the impairment assessment point but did indicate partial support. Likewise, the pollution index (organic enrichment) was above the reference assessment point. Finally, the disturbance index was well below the impairment criteria, although this metric is likely better suited to higher elevation steeper gradient streams. MT DEQ (2005) combined these four metrics into a MMI synthetic index of stream condition. Applying this to the LIBI data suggested that diatom communities were intact with good biological integrity and no overall impairment.

<u>Interpretation of Taxonomic Composition</u>
We next discuss select periphyton taxa within the LIBI samples (e.g., Bollman and Bowman 2007, Teply and Bahls 2006). Using the autecology of the dominant species in the samples allows additional interpretation and may help resolve the reasons or causes behind the increaser metrics or the more general indicators of ecological integrity. Diatoms ranked first in biovolume for both sample events at over 50% and coupled with the less well resolved tolerances for soft bodied algae in Montana streams we focus on these taxa.

A complete taxa list with counts and relative abundance values is given in Appendix D. We collected 108 unique taxa (largely identified to species) over the two sample events at LIBI. Community composition in the two periphyton samples from LIBI was fairly typical for the recent Little Bighorn River (L. Bahls, pers. comm., 2011).

Non-Diatom Algae
The periphyton community at LIBI consisted of diatoms, cyanobacteria, green and red algae. The cyanophytes (blue-green algae) *Homoeothrix janthina*, *Anabaena*, and *Leptolyngbya* were the most abundant soft-bodied taxa, ranging in RA from 11-47%. Potapova et al. (2005) presents water chemistry optima for several species of soft-bodied algae including *Homoeothrix janthina*. This species tends to occur at sites with relatively good water quality with larger substrates, but moderately high total nitrogen perhaps due to the absence of heterocytes in this organism, and therefore to its inability to fix free nitrogen. However, the red algae genus *Phormidium*, which contains several pollution-tolerant species,



IMAGES COURTESY OF REX LOWE AS OBTAINED FROM SPAULDING ET AL. (2010).

Figure 19. A common algae at LIBI, *Epithemia sorex*. Main image shows *E. sorex* epiphytic on a strand of *Cladophora* with the inset a scanning electron micrograph image of a single *E. sorex* valve. Scales of images differ.

was also common at 12% RA.

Diatoms
The diatom taxa with highest total count and relative abundance across both LIBI samples was Epithemia sorex at 25% relative abundance (Figure 19). It is on the sediment and nutrient increaser taxa lists for the warm water ecoregions increaser lists (Teply, 2010b; MT DEQ, 2011b). E. sorex is eutraphentic (prefers nutrient-enriched, eutrophic waters) and requires fairly high levels of dissolved oxygen. Its presence can suggest impairment by inorganic nutrients, but probably little or no impairment by organic nutrients. It is frequently very abundant as an epiphyte on *Cladophora* and other coarse filamentous algae in western rivers that are nitrogen limited. Diatoma moniliformis was also common in both years, with a relative abundance of 16-20%. *D. moniliformis* is a fairly common species across the West. It is on the sediment increaser taxa list for the for the Montana plains (Teply, 2010b; MT DEQ, 2011b). It tends to occur in systems with mid- to high-levels of fine sediment (as measured by percent embeddedness; data from Stoddard et al. 2005, as analyzed and presented in Spaulding et al.2010). The high abundances of these species (especially *E. sorex* and *D. moniliformis*) are the primary reason why the sediment increaser metric was so high, especially in 2009. *Nitzschia dissipata* was also relatively common in 2007. It is not included as either a nutrient or sediment increaser taxa (Teply, 2010b, MT DEQ 2011b). However, this species is

motile and can deal with mobile sand grains and increased fines. It favors slower current velocities where sediments are prone to accumulate. Finally, *Cocconeis pediculus* was relatively abundant in 2009. Like *E. sorex*, this species is primarily an epiphyte on *Cladophora* spp. (a filamentous green algae), which prospers mainly in nutrient-rich waters with slow to moderate current velocities where sedimentation is an issue.

Aquatic Invasive Species

There were no known zebra or quagga mussel (*Dreissena polymorpha*, and *D. rostriformis bugensis*) or rusty crayfish (*Orconectes rusticus*) occurrences in or near the Little Bighorn watershed (the mussels have been found outside Rocky Mountain National Park and the crayfish on the western slope of Colorado). Confirmed New Zealand mudsnail populations (*Potamopyrgus antipodarum*) in south east Montana and neighboring states from the USGS Nonindigenous Aquatic Species program (Benson 2011) are shown in Figure 20 (as of 2011). There are no known current populations at LIBI, but mudsnails have been documented on the Bighorn River below LIBI's sister park, Bighorn Canyon National Recreation Area. Mudsnails tolerate siltation, thrive in disturbed watersheds, and benefit from high nutrient flows. They have the ability to reproduce quickly and mass in high densities and can impact trophic dynamics of native trout fisheries and alter the physical characteristics of the streams themselves. Given these possible impacts and the suitability of the Little Bighorn to this species, we will closely watch for it in the future.

Didymo (*Didymosphenia geminata*) have also been confirmed in the Montana region from work conducted by the U.S .EPA (EPA 2012) the ROMN (in GLAC) and other partners (Figure 21). As of 2011 there were no known current populations on the Little Bighorn or in the watershed. Didymo is a diatom native to mountain habitats of North America and Europe (Blanco and Ector 2009). In recent years didymo has expanded into lower elevations, latitudes, and new regions of the globe (Kumar et al. 2009). In Montana, didymo was first reported in 1929 at Flathead Lake (Prescott and Dillard 1979) and has likely been present in the northern Rockies since at least the end of the last ice age, about 10,000 years ago (Bahls

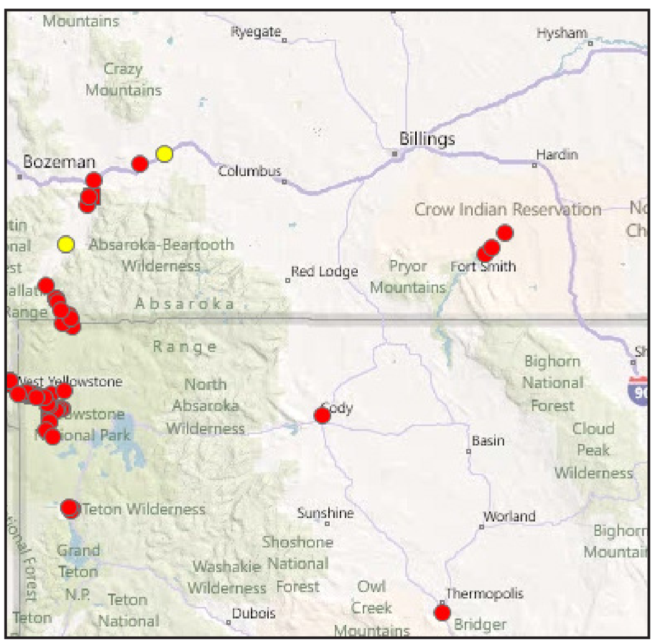


Figure 20. Point locations of the New Zealand mudsnail (*Potamopyrgus antipodarum*) in the south eastern Montana-northwestern Wyoming area. Red dots indicate established populations. Yellow dots indicate confirmed collections. Approximate location of LIBI is shown with the red star. Data are from several (uncoordinated) sample designs and therefore are not a valid sample of this region as a whole. Data span 2004-2009. Data and map courtesy of the USGS Nonindigenous Aquatic Species program

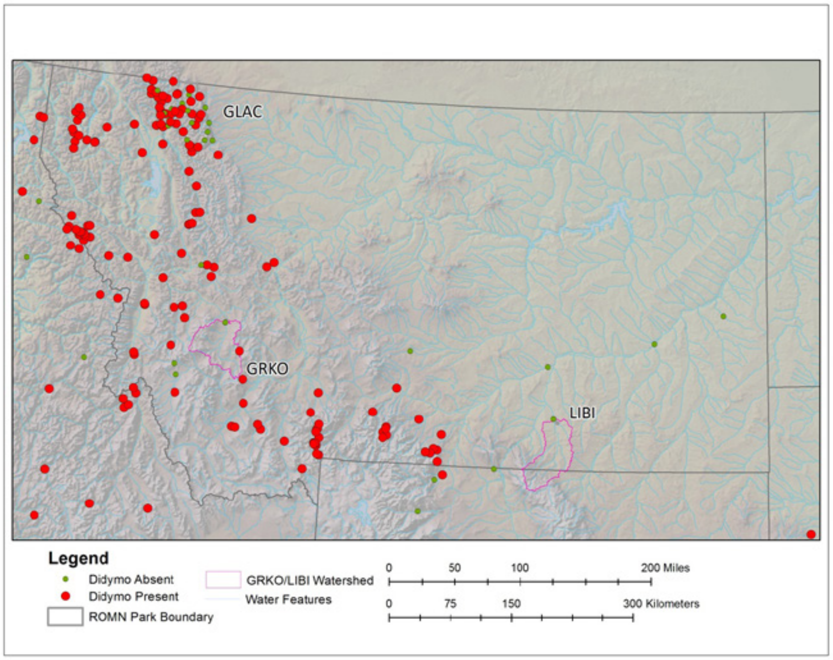


Figure 21. Point locations of confirmed presence of didymo (*Didymosphenia geminata*) in the Montana region. Data are from several (uncoordinated) sample designs and therefore are not a valid sample of this region as a whole. Data span 2004-2009. Records outside of Glacier National Park are based on data from USGS National Water Quality Assessment (NAWQA), EPA Environmental Monitoring and Assessment (EMAP), and samples from other studies and are courtesy Karl Hermann, Sarah Spaulding, and Tera Keller. Data in Glacier National Park are from ROMN SEI monitoring.

2007). Didymo can form extensive mats (or blooms), which can be several centimeters thick and up to 20 km (12 mi) in length (Blanco and Ector 2009). Larger blooms can inhibit growth of other algal species, change the composition of aquatic communities, decrease the amount of suitable spawning habitat for fish, and cause changes in stream chemistry (Spaulding and Elwell 2007). Blooms of didymo also greatly decrease the aesthetic appeal of streams, an important consideration for NPS. Schweiger et al. (2011) recently described the distribution and developed simple models of the drivers of didymo abundance in Glacier National Park (see Figure 21 for these data as presence/absence). As with mudsnails, given the possible impacts of this species, we will watch for it at LIBI but hopefully, the species will not continue to adapt to conditions characteristic of warmer water systems like the Little Bighorn.

Summary and Conclusions

This report presents data, results and select interpretations from ROMN SEI monitoring on the Little Bighorn River during 2007-2010 at LIBI. We employed several vital signs to monitor the status and trend (as possible) of stream condition. These included multiple measures of water and sediment physiochemistry, physical habitat, and biology (macroinvertebrate and diatom communities). The approach of the SEI protocol is to integrate or interpret these measures in concert as indicators of the ecological integrity of the system and to emphasize individual metrics that are likely direct estimators of integrity. We interpret results using a variety of assessment mechanisms including regulatory criteria (but in a non-regulatory way), other relevant assessment points from the literature and where possible, reference values derived from state and federal monitoring reference sites in the Northwestern Great Plains ecoregion. Because SEI monitoring is not regulatory in nature, we can consider assessment points that may have more of an ecological basis or are relevant to a specific LIBI resource management need.

Table 18 presents an overall assessment of the condition of the Little Bighorn in 2007 - 2010. In general, the river and its riparian corridor was largely intact and medium to high in quality. A few areas of concern might include some evidence of excessive fine substrates in littoral or shoreline areas, some non-reference aspects of the riparian corridor with some invasive plants of concern. The weight of biological evidence suggests a non-reference biological condition. However, the available biological metrics may not be well suited to the Little Bighorn and in general we have low to medium confidence in this interpretation (in other areas we have greater confidence in our assessment). The long-term trend in stream temperature suggests rising water temperature and reduced total flow - or a deteriorating condition (but the period of record is short). With this combination of results we feel the overall score (within the constraints of the Summary Condition process) is a “Caution/Intermediate”. We do not have enough data to speak on the trend in this overall condition. We have “Medium” confidence in these conclusions as discussed further below.

Confidence

The SEI protocol is based on established and accepted methods, used by many ROMN partners. Field methods and the analyses employed on these data were chosen because of their general ease of implementation and quality of the results. However, budget and other constraints do limit some uses of the data, especially so early in ROMN monitoring when we have a small temporal sample size, and the following briefly summarizes important caveats.

Table 18. Summary condition table excerpt for the overall assessment of the condition of the Clark Fork at GRKO in 2008-2010. We include example vital signs and indicators, a brief description of results and patterns, and symbolize the status, trend, and our confidence in those summaries. See the Executive Summary for the complete Summary Condition Table.

Vital Sign (Example Indicators)	Summary	Symbol
Overall ecological integrity	The ecological integrity of the Little Bighorn from 2007 to 2010 was largely intact and of medium to higher quality. Results were somewhat mixed, with high quality water physiochemistry and physical habitat, but the weight of biological evidence suggests a non-reference biological condition. However, the available biological metrics may not be well suited to the Little Bighorn and in general we have low to medium confidence in this interpretation (in other areas we have greater confidence in our assessment). We lack data to assess the overall trend in condition.	

Water Physiochemistry

Most water physiochemistry constituents are naturally variable seasonally or even daily and SEI survey methods may not capture some of this temporal variance. Water physiochemistry also has a high degree of spatial structure, with meaningful differences across macrohabitats within streams. Many of the chemistry parameters we include are likely conservative and may integrate across habitats. SEI base flow sample events are conducted when most biota are stressed (due to lower stream flow) or at key points in their life cycles. Water or sediment physiochemistry at this point in the hydrologic cycle may be a useful index of stress driving biological condition.

Finally, while the status of water physiochemistry is important, given its diel and seasonal fluctuations, it may not be as relevant as long term, seasonally adjusted trends. After we collect sufficient data at the SEI sentinel site we will conduct detailed trend analyses and we will continue to use USGS data where it is available to analyze for trend.

Habitat

The SEI protocol adopts a suite of field methods for habitat developed for regional surveys (i.e., EMAP). These methods are relatively simple and inexpensive. They have been shown to provide a diverse suite of useful data, with most metrics generated from these data having acceptable precision that allow meaningful comparisons across large numbers of sites within a region. However, these methods are not equivalent to an engineering grade survey for a specific stream site. Current SEI habitat results might prudently be confined to identifying severe cases of sedimentation, channel alteration, etc. in the Little Bighorn at LIBI. Greater confidence to discern subtle differences could be gained by using more precise field measurements of channel slope, bed particle size and bankfull dimensions, and by refining some of the adjustments in metric calculation for energy loss from channel form roughness (Kaufmann et al 2008).

Biology

The bioassessment models we use are of course imperfect. As with any modeling effort, there is error and uncertainty associated with data sampling and processing, model calibration, validation, and model use. The current MT DEQ Plains MMI had a discrimination efficiency of 77%, indicating that the MMI was unable to distinguish between reference and degraded sites in approximately 23% of the samples, which may be of some concern in our application to LIBI. As of mid-2012 MT DEQ was evaluating whether the model was appropriate for use in their program and is considering if taxa-level analysis might be more useful in eastern Montana (Dave Feldman, MT DEQ pers. comm, 2012). We therefore apply the Plains MMI to LIBI with caution. The Montana RIVPACS model is comparable to or better than most RIVPACS models in use in the U.S. and elsewhere in terms of model precision (Hawkins 2006). Good models typically have a standard deviation in O:E less than 0.18. The Montana model SD in O:E was 0.17 with the model accounted for ~88% of the explainable variability in taxonomic composition among samples. Moreover, because the OTUs used in RIVPACS modeling often represent relatively coarsely resolved taxa (e.g., many genera, some families, a few species), our assessments will be conservative with respect to what we would see with models based on species-level data (Hawkins et al. 2000). An important consideration in bioassessment using RIVPACS is the match or fit between an assessed site and the appropriate reference condition. The Little Bighorn at LIBI was within the experience of the RIVPACS model, suggesting that the environmental conditions that drive macroinvertebrate community assemblage were comparable to those seen in reference sites.

Finally, it is sometimes difficult using biological metrics to be diagnostic or to ascribe a causal relationship between a biological response and a stressor. While not necessarily needed from a strict long-term monitoring perspective focused on ecological integrity, knowing, at least in a correlative sense, what might be causing a lower quality biological status is useful for park management and interpretation for visitors. As we accrue more data and our understanding and modeling of the biological response in the Little Bighorn Fork improves, we may be able to make more definitive statements about why a particular response is seen at GRKO. Moreover, methods being developed for the ROMN wetland protocol on causal modeling (Grace et al 2012) may be applied to future SEI data to help refine our understanding of relationships in these data.

There is also a risk of disagreement in general conclusions when using multiple models. This happened at LIBI, with a difference between the MMI and the RIVPACS metrics (when using p>0.5). MT DEQ provides guidance for making decisions in these cases (Feldman 2006). All LIBI models met sample size requirements and site relevancy, but there is a greater degree departure from reference using O:E and more extreme departures are given greater weight by MT DEQ in resolving conflicts across metrics. Therefore, we conclude that a non-reference state as suggested by the variant of the O:E model used by MT DEQ likely characterizes the LIBI macroinvertebrate assemblage. This matches the general pattern when LIBI metrics are compared to ecoregion assessment points. However, given the lower discrimination efficiency of the Plains MMI model and the results for both MMI and O:E when all taxa are included, we do not have strong confidence in this conclusion.

Management Implications of SEI Results

Pending review and input from the park, the SEI results at LIBI will be applied toward:

1. Continued long-term monitoring of the ecological integrity of the Little Bighorn in LIBI, especially as a response to climate change;
2. Contributing to interpretative material for park visitors.
3. Assisting park staff and management in understanding stream geomorphology and substrate interactions, and how these might interface with bank sloughing;
4. Regulatory applications as needed (in collaboration with MT DEQ).

Understanding Climate Change

One of the most relevant applications of SEI monitoring in LIBI will be to helping the park understand any changes in the integrity of the Little Bighorn that might be due to climate change. This will of course take more and longer term data for SEI responses, although the USGS stream flow and water physiochemistry data from the Hardin USGS gauge are already offering some glimpses at possible climate mediated shifts in these responses.

Changes in stream hydrology and temperatures in the West over the past fifty years due to climate changes are well documented (Barnett et al. 2008) and these changes are expected to continue. Even modest ambient temperature increases in the western U.S. may cause significant changes to the hydrologic cycle, often manifested in earlier snowmelt, earlier ice-out on lakes, reduced summer base flows (Dettinger et al. 2004), a lower snowpack volume at lower to mid-elevations (Knowles et al. 2006), and increased flooding due to rain-on-snow events in winter (Heard 2005). Hydrographs (i.e., the magnitude and timing of spring run-off) will likely shift to earlier floods. These changes will, in turn, likely affect the seasonal dynamics of stream and riparian biota (Palmer and Bernhardt 2006). Climate may drive changes in water quality due to several mechanisms, such as stream temperature, increased erosion, and decreased dilution of pollutants. Decreases in snow cover and more winter rain on bare soil are likely to lengthen the erosion season, which can increase nutrient concentrations in streams. Predicted increases in the severity and frequency of floods may also contribute to increases in erosion, as well as affect ecological processes that are sensitive to changes in the probability distributions of high flow events such as habitat stability, biodiversity, and trophic structure (Hamlet and Lettenmaier 2007).

Whether climate change is having a measurable impact on the Little Bighorn in LIBI is unclear. In the northern and central Rockies, streamflow has generally shifted toward earlier peak runoff, which has been attributed to more precipitation falling as rain rather than snow and earlier snowmelt (Knowles et al. 2006, Mote et al. 2005). However, at LIBI the midpoint of annual discharge and the date of highest flows (not driven by ice jams) for two of the three water years (2009 and 2010) was later in the year than during the historic period of record. This suggests a hydrograph that may be shifting forward in time, with delayed runoff. There is also a suggestion that the LIBI hydrograph is becoming more variable. Finally, the marginal and small negative trend in discharge over the period of record from the Hardin gauge also fit this pattern. Importantly, it is unclear if the three recent water years at LIBI are aberrations from patterns in climate driven streamflow phenology seen across the west over longer time periods. More data will be required to test this.

Isaak et al. (2011) show an interesting pattern in stream temperatures across select Pacific Northwest streams from 1980 to 2009 (two of which were in Montana and one, the upper Missouri, may be similar to the unregulated Little Bighorn) with a cooling trend apparent during the spring and warming trends during the summer, fall, and winter. The amount of warming more than compensated for spring cooling to cause a net temperature increase, and rates of warming were highest during the summer. Warmer stream water, as we see a suggestion of in LIBI, can have a cascade of impacts on the condition of a river like the Little Bighorn. Increased temperatures can lead to oxygen depletion, a change in fish distribution, and a loss of some species of benthos and periphyton, especially those that are isolated in habitats near thermal tolerance limits or that occupy rare and vulnerable habitats (Williams et al. 2007). Fish such as sauger (*Sander canadensis*), a potential species of concern in Montana, may be experiencing or facing reduced distribution, potentially linked to water temperatures (McMahon and Gardner 2001). In contrast, many fish species that prefer warmer water, such as carp, may expand their ranges if surface waters warm (Battin et al. 2007). Warmer waters may also cause aquatic diseases and parasites to become more widespread (Hari et al. 2006).

Future Work

This effort has been, and will continue to be, a cooperative undertaking between ROMN staff; aquatic scientists, especially from USGS, the EPA, and MT DEQ; and most importantly, LIBI management and staff. Our results represent the efforts of many dedicated scientists and resource managers over several years and we feel are valid, representative and address our objectives. They should be useful for understanding and, within the constraints of the protocol, managing the Little Bighorn.

The future of the SEI protocol in LIBI includes several important actions. Primarily we must continue to accumulate and analyze SEI data relative to criteria and assessment points from state and developed from the ecoregion. These may help us focus on monitoring the most parsimonious and management relevant suite of indicators to evaluate the ecological integrity of the Little Bighorn in LIBI. We may want to consider improving a subset of the habitat methods. Our current protocol includes relatively simple and inexpensive approaches shown to provide a diverse suite of useful data. However, these methods are not equivalent to an engineering-grade survey of a specific stream site. More precise field measurements of channel slope, cross-section geometry, and bed surface particle size would be required to use some of our metrics in site-specific assessments at individual streams. Finally, we may want to consider including episodic monitoring over extended time periods of *in situ* parameters (pH, DO, conductivity, temperature) and adding turbidity to quantify shorter-term changes that may occur with the possible future restoration or more active management of the floodplain at LIBI.

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Appendix A: Field Method Overview and Justification

We present summaries of field data collection methods and a brief justification for the major responses we collect in the following sections. Schweiger et al. (In Review) presents full details for all methods.

Water and Sediment Physiochemistry

Water and sediment physiochemistry are indicators that have been historically used to monitor the condition of a stream; however, they are just two indicators we use to estimate "water quality" within the SEI protocol. We also rely on habitat and biological measures. Moreover, the sampling methodology we use for water physiochemistry has implications for data interpretation. Episodic grab samples represent conditions at the point and time of sampling; they do not represent the condition of the entire water body, spatially or temporally. We collected multiple water physiochemistry samples on the limbs of the hydrograph (rising, peak, falling, base, and winter) in order to better understand the range of conditions that can occur across a water year. A water year is defined as the 12-month period beginning October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. For example, the year ending September 30, 1999 is called the "1999" water year. Thus, important diel patterns in some water quality parameters are not captured. Over the duration of the LIBI SEI pilot we gradually increased sampling frequency from one to four times per year in an attempt to capture all of these phases of the water cycle at LIBI.

In situ

Four *in situ* (measured within the stream channel) core field parameters (temperature, pH, specific conductance, and dissolved oxygen) are measured as part of all funded NPS WRD water quality monitoring protocols. As such, these attributes contribute some measure of consistency and comparability of water quality conditions among multiple NPS monitoring programs (NPS 2002). The use of the word "core," however, does not imply that these parameters are more or less important than other parameters. In situ data were collected with a handheld multi-parameter probe (also known as a sonde). In 2007 and 2008 data were collected with an In Situ 9500. Beginning in 2009, all data were collected with a YSI ProPlus. These two instruments were compared in the lab before deployment, following WRD guidance, but were not used congruently in the field due to budget restrictions. We also collected continuous data on stream temperature using small sensors submerged near the bank at the bottom or lowermost part of the sample reach. All field methods follow NPS WRD protocols for quality assurance (i.e., calibration routines and criteria).

Water temperature is a critical variable controlling many ecosystem processes, both physical and biological, and it can impact almost all functions within an ecosystem (Allan 2004). Rates of most physical, chemical, and biological processes are strongly influenced by temperature. It is also a critical parameter for tracking climate change response in park ecosystems. Water pH (the measure of water hydrogen ion concentration) has many physical and biological effects. Most aquatic species occur within specific habitat envelopes of pH conditions, and changes in pH will likely result in changes in species assemblages. Specific conductance is the ability of a water body to conduct an electric current and is directly correlated with dissolved ion concentrations in water bodies. In essence, the more dilute the water, the lower the concentrations of dissolved salts and thus the lower the conductance. Changes in conductance suggest changes in major ions or nutrients, such as potassium, calcium, and other anions and cations. Dissolved oxygen is closely linked to physical and biological processes. For instance, respiration, photosynthesis, and atmospheric exchange (through turbulence in rapids and riffles) are the principle processes that affect or are

NPS/M STOPS

ROMN, LIBI, and EPA/USGS staff prepare to launch sampling rafts on the Little Bighorn River, 2009.

affected by dissolved oxygen concentrations. In addition to high water temperatures, high microbial activity, which is driven by organic pollution, drives demand for dissolved oxygen resulting in anoxic conditions. High oxygen levels are especially critical for the metabolism of aquatic insects and salmonid eggs.

Water and Sediment Grab Samples

Given similar parameters collected, analytical methods, application and interpretation of criteria, we group water and sediment physiochemistry together in the following sections. We use the less-common term “physiochemistry” because we include both physical (i.e., temperature) and chemical (i.e., nutrients) parameters in the group. We measured almost 60 parameters based on a variety of considerations. Parameters included 11 nutrients (and carbon), 11 major ions, 12 trace elements (both dissolved and total recoverable metals) in water, and 13 metals in sediment. Water samples were taken using single location, depth-integrated thalweg method. Bulk bed sediment samples were composited from seven to ten individual samples of fine-grained bed sediment collected by scooping material from the surfaces of representative deposits along pool or low-velocity areas at each transect location or at ad hoc locations near where water samples were collected. Sediments were not sieved. All ROMN SEI Quality Assurance/Quality Control (QAQC) field procedures were followed.

Samples were analyzed at four laboratories depending on the sample date and parameter. In 2008, all samples went to the Flathead Lake Biological Station (FLBS) lab. In 2009 and 2010, all nutrient samples, major elements and some trace elements went to the University of Colorado Kiowa lab. Most trace elements in water during 2009, and all sediment parameters in 2009 and 2010 were analyzed by the EPA Region 8 lab. A few trace elements in 2010 were analyzed by the Environmental Testing Corporation lab. Each lab was selected given expertise and operational constraints within the SEI protocol development at LIBI. Each lab followed rigorous internal QAQC that ensured comparability across lab results. Future monitoring at LIBI will use the Kiowa and EPA labs only.

Sampled nutrients include the dominant forms of nitrogen and phosphorous (both total and dissolved). We also sampled organic and total dissolved carbon. Nutrients may be limiting in aquatic ecosystems, controlling ecosystem productivity, as well as being indicators of eutrophication caused by external stressors (e.g., atmospheric deposition or visitor use activities). Total organic carbon and dissolved organic carbon are essential components of the carbon cycle in streams and their watershed. Dissolved organic matter may impact contaminant transport and drinking water quality.

Major ions include two predominant anions (sulfate and chloride) and four cations (calcium, sodium, potassium, and magnesium). These six ions, along with carbonates, make up most of the ions in stream water. These ions are important indicators of the watershed context of the stream, with different ion concentrations reflecting variation in geology, vegetation, and weathering processes. However, sulfate is also common as an indicator of pollution (e.g., from mining waste or agricultural runoff). We also include total suspended solids (TSS). High concentrations of particulate matter can cause increased sedimentation and siltation in a stream, which in turn can impact important habitat areas for aquatic life. Suspended particles also provide attachment places for other pollutants, such as metals and bacteria. Trace elements in water include those that typically occur only in minute concentrations, such as metals. However, contamination of a stream with trace metals is not always detectable in the water column because they may have precipitated or adsorbed to organic particulates or fine sediments. Therefore, we also sample sediments deposited from the water column to detect trace metal contaminants. Many metal ions are lethal to fish and other aquatic life forms. Metals often are bio-concentrated, leading to increasing concentrations in species higher in the food chain. We include total mercury in the suite of parameters analyzed in the sediment samples. Mercury has no known metabolic purpose and is toxic to living organisms. In humans, mercury adversely affects the central nervous system. Mercury can be converted from inorganic compounds, which we measure, to organic forms such as methylmercury, which is easily absorbed by organisms, but harder and more expensive to monitor.

Stream Productivity

Two indicators of stream productivity were also created from the composite periphyton samples (see below): chlorophyll-a and ash free dry mass (AFDM). Known volumes were filtered from the composite samples in the field and frozen for later analysis.

AFDM and chlorophyll-a samples were processed using standard methods (APHA 1995). Filters were pre- and post-weighed after combustion in a muffle furnace for AFDM. Chlorophyll-a was extracted and analyzed via fluorescence. AFDM and chlorophyll-a concentration per unit area were generated using the area and volume of sample collected and volume of sample filtered. Note that this method is not the same as the current protocol used by MT DEQ (Suplee and Suplee 2011).

We present the stream productivity measures within the water chemistry section as they are used as indicators of general nutrient loads within a stream. Nutrient concentration is correlated with ecosystem disturbance (e.g., deforestation and agriculture) as periphyton production declines with increasing river size and turbidity (Naiman et al. 1993). Chlorophyll-a typically ranges from 0.5 to 2% of total algal biomass at a typical stream (APHA 1995), but this ratio varies with taxonomy, light, and nutrients. Ash-free dry mass is also a measure of the organic matter in samples, but in contrast to chlorophyll-a, where only photosynthetic algae are the source, AFDM also includes bacteria, fungi, small fauna, and organic detritus. Together these measures complement the species list-based diatom metrics described above and may be especially important in studies that address potential nutrient enrichment or toxicity.

Physical Habitat

Note: much of the approach in the SEI protocol to habitat characterization and the narrative used in this report for describing physical habitat methods, metrics, and interpretation is based on similar treatments graciously provided by researchers from the EPA (Kaufmann et al. 1999, Stoddard et al. 2005).

Quantitative characterization of stream physical habitat is a core element of long-term monitoring of the Little Bighorn River at LIBI. Stream habitat is an important component of aquatic resource monitoring because it can help describe the context or template for ecosystem function and condition (Frissell et al. 1986, Kaufmann et al. 1999). Habitat is often a key covariate of stream biology and can help us understand patterns in aquatic communities by helping predict the presence/absence of organisms. It may also help explain important spatial variation in other aspects of stream community structure. Additionally, habitat is a useful monitoring endpoint itself (e.g., increases in the percent of fine sediments) and can help us understand changes in stressors such as particular land uses outside or inside a park, including possible visitor impacts.

The physical habitat components of the ROMN SEI protocol are based on research conducted by the EPA over the last two decades (Kaufmann et al. 1999, Stoddard et al. 2005). Many of these methods have also been adopted by MT DEQ. Importantly, our approach confines observations to habitat characteristics themselves versus subjective field evaluation of the quality of habitat (e.g., SEI methods do not include crew members determining in the field if some aspect of stream habitat is in "good condition" or not). Patterns and trends in habitat characteristics developed from SEI data may themselves be of interest, as well as any association with stream biota, watershed land use, park visitation, and other factors. Furthermore, an objective habitat quality index may be derived by ascribing quality scoring to the habitat measurements as part of the data analysis process (Kaufmann et al. 1999, Simonson et al. 1994, Meador et al. 1993). We feel the extra fieldwork and analyses required to deal with these data are worth the effort. As with several other aspects of the SEI protocol, using these methods also allows us to connect our work to other similar monitoring programs in stream and rivers across Montana and the West.

We included five major classes of physical habitat characterization at LIBI. The first component, a channel and riparian characterization, included measures and visual estimates of channel dimensions, substrate, fish cover, bank characteristics, riparian vegetation structure, nonnative invasive plants, and evidence of human disturbances. The human disturbance measures include in channel, bank side, and indicators of human-caused stress in the nearby floodplain. These data were obtained at each of the 11 equally spaced transects established within the sampling reach. The second component was a thalweg profile or a longitudinal survey of depth,

Table A1. Categories of ROMN SEI physical habitat measures.

Component	Description
Substrate, Channel, and Riparian	Up to 11 cross-section transects (with an additional 20 for substrate size) placed at equal intervals along reach length are used to measure: • Channel cross-section dimensions, bank height, bank undercut distance, bank angle, slope and compass bearing (backsight), and riparian canopy density (densiometer). • Substrate size class and embeddedness; areal cover class and type (e.g., woody trees) of riparian vegetation in canopy, mid layer, and ground cover; areal cover class of fish concealment features, aquatic macrophytes, and filamentous algae. • Presence and proximity of human disturbances, presence of large trees, and presence of target invasive plants.
Thalweg Profile	• Measure maximum depth, classify habitat and pool-forming features, presence of backwaters, side channels, and deposits of soft, small sediment at 10-15 equally spaced intervals between each of 11 channel cross-section transects (100 or 150 individual measurements along entire reach). • Measure wetted width and evaluate substrate size classes at 11 regular channel cross-section transects and midway between them (for 21 width measurements).
Woody Debris Tally	• Between each of the channel cross-sections, tally large woody debris numbers within and above the bankfull channel according to length and diameter classes (10 separate tallies).
Assessment of Channel Constraint, Debris Tor-ents, and Major Floods	• After completing thalweg and transect measurements and observations, identify features causing channel constraint, estimate the percentage of constrained channel margin for the whole reach, and estimate the ratio of bankfull/valley width. Check evidence of recent major floods and debris torrent scour or deposition.
Hydrology	• Instantaneous measure of discharge with each full sample event. • Continuous USGS data on discharge at nearby gauge(s), if present.

habitat class, presence of soft/small sediment deposits, and presence of off-channel habitats at 100 equally spaced intervals along the thalweg (deepest part of the channel) between the two ends of the sampling reach. Wetted width was measured and substrate size evaluated at at the 11 transects. Measurements of stream slope and compass bearing between stations were obtained in a GIS, providing information necessary for calculating reach gradient, residual pool volume, and channel sinuosity. The third component was data on woody debris at each of 10 segments of stream plots located between the 11 regular transects. The fourth component, assessment of channel constraint, debris torrents, and major floods, was an overall assessment of these characteristics for the whole reach. Finally, the fifth component, stream discharge was measured at the time of each full sample event within the sample reach using a Flowtracker and taken from the USGS gauge in Hardin as a time series of continuous data.

Macroinvertebrates

Stream macroinvertebrates, also known as benthos, include crustaceans, mollusks, aquatic worms, and most importantly (because of their dominance and ecological function), the immature forms of aquatic insects such as stonefly and mayfly nymphs. The term "benthic" means "bottom-living," as these organisms usually inhabit stream bottoms for at least part of their life cycle.

ROMN SEI benthos sample collection and processing follow well-established and standardized EPA, USGS, and MT DEQ methods and are described in detail in Schweiger et al. (In Review). Quantitative benthos samples were composited from eleven 1 ft^2 subsamples taken at each transect along the reach using a D-net with 500 µm mesh net (Figure A1). Each subsample was collected over a constant time (30 seconds). Samples were preserved in 95% alcohol (ETOH) for later identification. Samples were spread on a gridded tray or Caton-type splitter and picked from a randomly selected subset of grid cells until 600 organisms were removed (a search for large, rare specimens was also conducted in the whole sample). At least 10x magnification was used to sort invertebrates from debris. All specimens were identified to the lowest practical level or as specified in Schweiger et al. (In Review). Voucher specimens, including head capsule mounts for midges, are housed with NPS. Nomenclature follows the Integrated Taxonomic Information System. All identifications were cross-walked to Operational Taxonomic Units (OTUs) as developed by MT DEQ (Jessup et al. 2006) used to standardize identifications to a consistent level for some analyses and to NPSpecies nomenclature.

NPS/M. STICHMAN

Figure A1. Billy Schweiger (NPS, ROMN) collects macroinvertebrates on the Little Bighorn in 2007 using the standardized methods of the SEI protocol.

Macroinvertebrates are among the most widely used organisms for bioassessment because they can be sampled relatively efficiently and effectively (Resh and Jackson 1993); they are widespread in aquatic environments (Merritt et al. 2007), there are a large number of species that have a wide range of responses to environmental impacts (Resh et al. 1995), and since they are relatively sedentary, they can be used to determine the spatial extent of impacts. In addition, since macroinvertebrates are relatively long-lived, community response can integrate the high temporal variability associated with traditional physical and chemical analyses (Rosenberg and Resh 1996).

Periphyton

Periphyton includes algae, fungi, bacteria, and protozoa associated with channel substrates. Periphyton can be further grouped into growth forms, either as microalgae (microscopic, appearing as pigmented accumulations or films attached to submerged surfaces, typically single-celled algae), or macroalgae (visible without magnification, typically filamentous). Note that, while all periphyton algae taxa are included in SEI monitoring, diatoms (algae with hard, silica "shells") may be more useful as ecological indicators because they are found in abundance in most stream ecosystems, have a well understood range in tolerance to stressors, and are the focus of other similar monitoring efforts in the west (Spaulding et al. 2010).

ROMN SEI periphyton sample collection and processing follow well-established and standardized EPA, USGS, and MT DEQ methods and are described in detail in Schweiger et al. (In Review). Periphyton samples were composited from eleven subsamples taken at each transect along the reach. The specific method used depended on the dominant substrate type present at the chosen microhabitat. For erosional habitat, a piece of cobble within 50 cm of the surface was randomly chosen and a small known area of the "sunny side" was scraped of all benthic algae. For depositional habitat a small area of organic and mineral fines was vacuumed up with a syringe. A known volume from this composite was preserved with M-fixative (Lugols and dilute formalin) for later identification. The composite field samples were well mixed in the lab, sub-sampled, cleaned with nitric acid digestion and mounted on four slides using Naphrax. A Palmer-Maloney counting chamber count of 300 soft-bodied algae cells at 400x and a proportional count of 600 diatom valves (300 cells) along a scribed line with a random start was then conducted. A 100x scan and count of all valves present on the entire slide for Didymosphenia geminata and any novel taxa not in the focal search was conducted. All specimens were identified to species. Voucher slides are housed with NPS. Nomenclature follows the Montana Diatom Database (Bahls 2004) as there is not well developed taxonomic data in ITIS for algae. Any taxon that is identified in ITIS is crosswalked to the nomenclature used in our analyses. Moreover, all taxa are crosswalked to NPS's NPspecies nomenclature although many diatoms and algae are not yet included in NPSpecies.

Periphyton has important functions in aquatic habitats as producers of organic matter and plays a vital role in inorganic nutrient retention, transfer, and cycling (Stevenson and Smol 2003). Periphyton are useful indicators of environmental condition because they respond rapidly and are sensitive to a number of anthropogenic disturbances, including habitat destruction, contamination by nutrients, metals, herbicides, hydrocarbons, and acidification (e.g., Hill et al. 2003). In streams where flow and substratum characteristics create efficient interactions between water and the benthic periphyton assemblage, benthic algae typically reflect recent water chemistry (Lowe and Pan 1996). Periphyton assemblage composition is strongly influenced by land-water interactions, and also by stream size and the level of human disturbance.

Appendix B: Macroinvertebrate and Diatom Bioassessment Metrics

The following present summaries of the bioassessment metrics used to summarize macroinvertebrate and diatom assemblage samples collected at LIBI.

Macroinvertebrate Multimetric Index of Biotic Integrity

Multimetric or Indices of Biotic Integrity (MMI; Karr and Chu 1997) models are based on the presence/absence or sometimes relative abundance of taxa in a sample. Often taxa presence/absence or abundances are weighted based on autecological attributes (i.e., the tolerance of a taxon to a specific environmental condition such as sediment or nutrient concentration). Individual metrics (i.e., the proportion of a community that consists of taxa that are tolerant of high metal concentrations) that individually respond to measures of stress in a stream are combined into a synthetic composite index. Metrics that describe characteristics of biota that change in predictable or interpretable ways with anthropogenic stress (stream physiochemistry, habitat conditions, landscape composition, etc.) are ideal and selected for inclusion in the final model (Barbour et al. 1999). MMI models are empirical in that they are built from and calibrated by streams that are known to be in reference or degraded condition.

Jessup et al. (2006) develop MMI models for macroinvertebrates within the state of Montana. As of 2012 MT DEQ was updating and evaluating these models and the ROMN will use new versions of these tools as available in future assessments. Note that even if MT DEQ elects to discontinue use of a MMI, NPS may still use the model. The MT DEQ MMI models discriminate well between reference and degraded sites, are ecologically meaningful (mechanisms of responses can be explained), and represent diverse types of information (multiple metric categories). LIBI falls in the Northwestern Great Plains ecoregion where the MT DEQ applies the Eastern Plains version of the MMI. This model includes five component metrics: EPT taxa richness, percent Tanypodinae, percent Orthocladiinae of Chironomidae, predator taxa richness, and percent filterers and collectors. Note that all macroinvertebrate tolerances used in the model were derived from a suite of references and are specific for Montana (Plafkin et al. 1989, Bukantis 1998, Relyea et al. 2000, Brandt 2001, Merritt et al. 2007, W. Bollman pers. comm., 2011). We do present and interpret summaries of the five component metrics in the MMI as they often help interpret the more general index.

River Invertebrate Prediction and Classification System

The River Invertebrate Prediction and Classification system (RIVPACS) (Hawkins et al. 2000) was used to predict the Expected (E) macroinvertebrate taxa at the LIBI SEI site. RIVPACS models predict the specific taxa that should occur at a site given its natural (i.e., reference) environmental characteristics. Specifically, these models describe how probabilities of capture of all taxa of interest vary across naturally occurring environmental gradients. Expected taxa are those specific taxa that should occur in a sample collected from a site with specific environmental features assuming that site was in reference condition. By sampling the actual or observed (O) assemblage at the site, the simple ratio of O and E estimates the taxonomic completeness of the assemblage. This is a fundamental aspect of biological integrity. The O:E ratio is both a site-specific and standardized index with values that theoretically range from 0 to 1. Values of 1 imply reference conditions and values <1 imply biological impairment. RIVPACS models are calibrated only with reference site data, and the accuracy and precision of RIVPACS assessments depend solely on how well models predict the taxa expected under reference conditions. If reference sites are not in natural condition, then models predict the biota that should occur given the quality of the sites used in modeling.

Jessup et al. (2006) develop a RIVPACS models for macroinvertebrates within the state of Montana. MT DEQ (2012) presents an updated version of the model models and the ROMN will use these tools in future assessments. The Montana RIVPACS model is a state scale model; however, a single model (Hawkins et al. 2000) can be used for an entire state if the effect of natural gradients can be adequately modeled, as it was in Montana (Jessup et al. 2006). This is an alternative way to measure the compositional dissimilarity between an observed and expected assemblage and may perform better as it can include low-probability taxa without reducing the power to detect non-reference conditions (Van Sickle 2008, MT DEQ 2012c).

In general, the performance of the Montana RIVPACS model is comparable to or better than most RIVPACS models in use in the U.S. and elsewhere in terms of model precision (Hawkins 2006). Good models typically have O:E standard deviations less than 0.18 and the Montana model was 0.17. The model accounted for 76% of the variation in O and the slope of the relationship was not different from 1. In general, O:E values effectively discriminated the stressed sites from the reference sites, especially for the upland streams in western Montana and the valley streams of the Northwestern Great Plains (where LIBI falls).

Other Macroinvertebrate Metrics

There are many "classic" metrics used in monitoring by several agencies over the last decade or two. These include other variants on the current MMI constructed following similar methods as the current MMI, but with different scoring criteria and component metrics. Given LIBI's intermediate elevation and setting in a mountainous valley floor we use the Valley/Foothill model from Bollman (1998).

The Karr Benthic Index of Biotic Integrity (B-IBI) is a MMI developed at a regional scale that has shown a surprising degree of applicability to assessments across a broad variety of stream types (Karr 1998). Karr is considered the seminal author on the MMI approach and the B-IBI model has received much review and use. The theoretical scale of the index is 0 to 100 with higher values indicating more impaired or disturbed communities. Its assessment points are simple percentiles (that decrease with increasing disturbance) and have no formal meaning within MT DEQ.

The Hilsenhoff Biotic Index (HBI) is another regionally scaled metric that has demonstrated a broad degree of applicability in bioassessments. It was originally intended as an assay of low dissolved oxygen caused by organic loading (Hilsenhoff 1987) but it may be sensitive to the effects of impoundment, thermal pollution, and some types of chemical pollution (Hilsenhoff 1998, Hooper 1993). It is similar to many other tolerance indices discussed below in that a tolerance values are developed for taxa and then applied as weighted sums based on occurrence within a sample. MT DEQ adjusted HBI tolerance scores for taxa in Montana and the HBI actually appears as a constituent metric in both the current and historic mountain MMI (Bukantis 1998, Jessup et al. 2006) used in Glacier National Park. However, in Montana's montane foothills (where LIBI occurs), the HBI was demonstrated to be significantly associated with conductivity, pH, water temperature, sediment deposition, and the presence of filamentous algae (Bollman 1998). The theoretical scale of the index is 0 to 10 with higher values indicating communities more tolerant of organic pollution. Assessment points in the HBI metric (which increase with organic pollution) are largely derived from professional judgment and have no formal meaning with MT DEQ.

The Fine Sediment Biotic Index (FSBI; Relyea et al. 2000) is based on tolerance scores for macroinvertebrates in Montana. FSBI increases with sediment intolerance (higher scores will contain more taxa that are intolerant to increased sediment or fines), with assessment point levels set by professional judgment (Relyea et al. 2000). The theoretical scale of the index is 0 to 10 with higher values indicating communities more tolerant of fine sediment. MT DEQ does not use the FSBI in any formal way. Moreover, assessing differences between natural levels of bed load sediment and anthropogenically increased levels may be difficult given fine scale spatial structure in stream habitat (Relyea et al. 2000). However, Bollman and Bowman (2007) suggest the index has promise as a screening filter for characterizing site sediment impairment.

The Metal Tolerance Index (MTI) metric quantifies changes in community composition attributable to metals pollution. The format and calculation is similar to the HBI (see above), with tolerance values assigned to each taxon based on sensitivity to metals rather than organics. The theoretical scale of the index is 0 to 10 with higher values indicating communities more tolerant of metals pollution. McGuire (2010) suggests that MTI values for communities dominated by species intolerant of metals are less than 4 while values for communities composed of only the most metals-tolerant species approach 10. Metals tolerance values for most taxa were developed from (Ingman and Kerr 1989) and (McGuire 1987 and 1989). The MTI was developed for the Little Bighorn River and we use it with caution in LIBI.

Finally, the Temperature Index (Brandt 2001) developed for Idaho streams (but applicable to northwestern streams in general; Bollman and Bowman 2007) was around 16 (equivalent to a stream temperature of 16°C). Scores (really a mean stream temperature optima for taxa in a sample) increase with warmer water, with lower scores characterizing sites with a higher relative abundance of stenothermic (or cold tolerant taxa).

Diatom Increaser Models

The State of Montana's current approach to bioassessment using diatoms is based on stressor-specific increaser diatom taxa, as described in Teply (2010a, 2010b). Metrics derived from these taxa are used as a diagnostic tool (along with others) in stressor specific assessment. Briefly, from Teply (2010b) increaser taxa were identified from a large sample of sites across the state with known impairments. Taxa that, as a group, exist in detectable amounts and demonstrate a meaningful, measurable and significant response to sediment (in the Middle Rockies or nutrients and sediment (in the Northern Great Plains) were identified on a specific list based on stream groups (derived using the MT DEQ fisheries classification and level III and level IV ecoregions following the same structure than the MT DEQ nutrient assessment methodology), Discriminant analysis was then used to evaluate the ability of the total relative abundance (RA) of taxa on the Increaser Taxa list to discriminate between impaired and non-impaired streams, and to provide a probability of impairment for a given RA. A single criterion set by MT DEQ at ≥51% suggests the probability of impairment for sediment in the river (MT DEQ 2011b).

Other Diatom Metrics

Bahls (1993) developed a suite of diatom metrics for MT DEQ based on common community level measures, species autecology or tolerance scores of groups of diatom species. Diatom species tolerances used in these metrics follow Bahls (2004) and are specific to Montana. Metrics included Shannon diversity, a Pollution Index (a composite numeric expression of the pollution tolerances assigned by Lang-Bertalot (1979) to common diatom species), a Siltation Index (sum of the percent abundances of species in the genera *Navicula*, *Nitxschia*, and *Surirella* predominantly motile taxa that are able to maintain their positions on the substrate surface in depositional environments), and a Disturbance Index (percent abundance of *Achnanthes minutissima* which resists chemical, physical and biological disturbances in the form of metals toxicity, substrate scour by high flows and fast currents). The metrics were intended to allow an assessment of the biological integrity of streams within plains and mountain bioregions. Assessment points based on the distribution of metric values measured in least-impaired reference streams (Bahls et al. 1992) and metric values measured in streams that are known to be impaired by various sources and causes of pollution (Bahls 1993). As with the non-current increaser metrics, we feel these metrics are useful in that they characterize basic aspects of the diatom community and build upon the long-standing history of algae-based bioassessment.

Appendix C: Taxa Lists

The following tables list taxa collected at LIBI SEI sample events in 2007 and 2009.

Macroinvertebrates

Table C1 presents the list of macroinvertebrate taxa from 2007-2009 sampling.

Table C1. Macroinvertebrate taxa list and relative abundances from LIBI SEI sample events in 2007-2009. Counts are followed by the relative abundances (in parentheses) within each sample. **Bold values indicate dominant (>~10% relative abundance) within a sample.** Benthos taxa were identified by multiple taxonomist so we use Operational Taxonomic Units (OTUs; see text) to collapse identifications to comparable values. A (blank) family indicates the level of identification was above family.

Family	Taxa (OTU)	Level of ID	Sample Date 10/04/2007	Sample Date 8/11/2009	Total Count
Baetidae	*Acentrella*	Genus	2 (0.17)	9 (1.7)	11
	Baetidae	Family	11 (0.93)	18 (3.4)	29
	Baetis	Genus	3 (0.25)	15 (2.83)	18
	Baetis flavistriga	Species	12 (1.02)		12
	Centroptilum	Genus	1 (0.08)		1
Baetiscidae	*Baetisca*	Genus	1 (0.08)	2 (0.38)	3
Belostomatidae	*Belostoma*	Genus	2 (0.17)		2
Ceratopogonidae	Ceratopogonidae	Family	5 (0.42)		5
Chironomidae	Chironomidae	Family	56 (4.76)		56
	Cricotopus	Genus		14 (2.64)	14
	Cricotopus/Orthocladius	Subfamily		5 (0.94)	5
	Cryptochironomus	Genus		1 (0.19)	1
	Microtendipes	Genus		5 (0.94)	5
	Nilotanypus	Genus		1 (0.19)	1
	Parakiefferiella	Genus		5 (0.94)	5
	Pentaneura	Genus		1 (0.19)	1
	Polypedilum	Genus		14 (2.64)	14
	Procladius	Genus		1 (0.19)	1
	Rheotanytarsus	Genus		1 (0.19)	1
	Stempellina	Genus		3 (0.57)	3
	Stempellinella	Genus		2 (0.38)	2
	Tanypodinae	Subfamily		1 (0.19)	1
	Tanytarsus	Genus		1 (0.19)	1
	Thienemanniella	Genus		1 (0.19)	1
	Thienemannimyia	Group		5 (0.94)	5
Coenagrionidae	Coenagrionidae	Family	2 (0.17)	2 (0.38)	4
Crambidae	*Petrophila*	Genus	1 (0.08)	2 (0.38)	3
Elmidae	*Dubiraphia*	Genus	15 (1.27)	15 (2.83)	30
	Microcylloepus	Genus	36 (3.06)	22 (4.15)	58
	Ordobrevia	Genus	25 (2.12)		25
Empididae	*Hemerodromia*	Genus	4 (0.34)		4
Ephemeridae	*Ephemera*	Genus		13 (2.45)	13
	Ephemera simulans	Species	5 (0.42)		5
Gomphidae	Gomphidae	Family		2 (0.38)	2
Heptageniidae	Heptageniidae	Family		14 (2.64)	14

Table C1. *Macroinvertebrate taxa list and relative abundances from LIBI SEI sample events in 2007 and 2009 (continued).*

Family	**Taxa (OTU)**	**Level of ID**	**Sample Date**		**Total Count**
			10/04/2007	**8/11/2009**	
Hydropsychidae	*Ceratopsyche*	Genus		4 (0.75)	4
	Cheumatopsyche	Genus	**508 (43.16)**	11 (2.08)	519
	Hydropsyche	Genus	**106 (9.01)**		106
	Hydropsychidae	Family	29 (2.46)	1 (0.19)	30
Hydroptilidae	*Hydroptila*	Genus	1 (0.08)	32 (6.04)	33
Leptoceridae	Leptoceridae	Family		2 (0.38)	2
	Nectopsyche	Genus		15 (2.83)	15
	Oecetis	Genus	1 (0.08)	6 (1.13)	7
Leptohyphidae	*Tricorythodes*	Genus	**111 (9.43)**	**104 (19.62)**	215
Leptophlebiidae	Leptophlebiidae	Family		3 (0.57)	3
	Neochoroterpes	Genus	**160 (13.59)**		160
	Paraleptophlebia	Genus		1 (0.19)	1
Naididae	*Nais*	Genus		21 (3.96)	21
Philopotamidae	*Dolophilodes*	Genus	1 (0.08)		1
Simuliidae	Simuliidae	Family	24 (2.04)		24
	Simulium	Genus		3 (0.57)	3
Tabanidae	Tabanidae	Family	1 (0.08)		1
Tipulidae	*Dicranota*	Genus	1 (0.08)	4 (0.75)	5
	Tipulidae	Family	1 (0.08)		1
Tubificidae	Tubificidae	Family		12 (2.26)	12
Miscellaneous	Acari	Subclass	13 (1.1)		13
	Ambrysus	Genus		2 (0.38)	2
	Calopterygidae	Family		3 (0.57)	3
	Clitellata	Class	14 (1.19)		14
	Ephemeroptera	Order	4 (0.34)		4
	Ephoron	Genus		4 (0.75)	4
	Fallceon	Genus		**90 (16.98)**	90
	Hygrobatidae	Subclass		1 (0.19)	1
	Ithytrichia	Genus		2 (0.38)	2
	Maccaffertium	Genus	19 (1.61)		19
	Mayatrichia	Genus		1 (0.19)	1
	Naididae	Family		2 (0.38)	2
	Stenelmis	Genus		31 (5.85)	31
	Turbellaria	Class	2 (0.08)		2
			1177 (2.94)	530 (2)	1707

Diatoms

Table C2 presents the diatom species detected in the 2007-2009 sampling.

Table C2. Diatom species list and abundance from long-term stations from LIBI SEI sample events in 2007-2009. Counts are followed by the relative abundances (in parentheses) within each sample. **Bold values indicate dominant (>10% relative abundance) within a sample.** Nearly all diatoms were identified to the species level by a single taxonomist so we do not require OTUs (see text). P indicates the taxon was present in a whole slide search (P is arbitrarily given a count of 0.5).

Taxa	Sample Date		Total Count
	10/4/2007	8/11/2009	
Achnanthidium deflexum		2 (0.33)	2
Achnanthidium eutrophilum		2 (0.33)	2
Achnanthidium minutissimum	21 (3.1)	12 (2)	33
Amphipleura pellucida	39 (5.76)	3 (0.5)	42
Amphora copulata	0.5 (0.07)		0.5
Amphora inariensis	2 (0.3)		2
Amphora pediculus		27 (4.5)	27
Biremis circumtexta		2 (0.33)	2
Caloneis amphisbaena	1 (0.15)		1
Caloneis silicula	2 (0.3)		2
Cocconeis pediculus	14 (2.07)	30 (5)	44
Cocconeis placentula	5 (0.74)		5
Cocconeis placentula v. *lineata*		3 (0.5)	3
Cyclostephanos invisitatus	2 (0.3)		2
Cyclotella meneghiniana	1 (0.15)		1
Cymatopleura elliptica	0.5 (0.07)		0.5
Cymatopleura solea	1 (0.15)		1
Cymbella affinis		5 (0.83)	5
Cymbella excisa	69 (10.18)		69
Cymbella subturgidula		2 (0.33)	2
Diatoma mesodon		1 (0.17)	1
Diatoma moniliformis	139 (20.52)	101 (16.83)	240
Diploneis pseudovalis		4 (0.67)	4
Diploneis puella	8 (1.18)		8
Encyonema reichardtii		2 (0.33)	2
Encyonema silesiacum	3 (0.44)		3
Encyonema triangulum	0.5 (0.07)		0.5
Encyonema ventricosum	0.5 (0.07)		0.5
Encyonopsis krammeri		2 (0.33)	2
Encyonopsis microcephala		2 (0.33)	2
Encyonopsis subminuta	23 (3.39)		23
Eolimna minima	2 (0.3)		2
Epithemia sorex	2 (0.3)	148 (24.67)	150
Fragilaria capucina	0.5 (0.07)		0.5
Fragilaria vaucheriae morphotype A GLAC LLB	10 (1.48)		10
Gomphoneis olivaceum	8 (1.18)		8
Gomphonema kobayasii	7 (1.03)	6 (1)	13
Gomphonema longilineare		2 (0.33)	2
Gomphonema minusculum		4 (0.67)	4
Gomphonema minutum		17 (2.83)	17

Table C2. *Diatom species list and abundance from long-term stations from GRKO SEI sample events in 2008 and 2009 (continued).*

Taxa	Sample Date		Total Count
	10/4/2007	8/11/2009	
Gomphonema olivaceum		5 (0.83)	5
Gomphonema parvulius		2 (0.33)	2
Gomphonema parvulum	0.5 (0.07)		0.5
Gomphonema pumilum	21 (3.1)		21
Gomphonema subclavatum	0.5 (0.07)		0.5
Gyrosigma obscurum		2 (0.33)	2
Mastogloia smithii	2 (0.3)		2
Melosira varians		1 (0.17)	1
Navicula canalis	11 (1.62)	17 (2.83)	28
Navicula capitatoradiata	4 (0.59)		4
Navicula caterva		2 (0.33)	2
Navicula cryptotenella	22 (3.25)	23 (3.83)	45
Navicula cryptotenelloides	44 (6.49)		44
Navicula erifuga	9 (1.33)	2 (0.33)	11
Navicula germainii	6 (0.89)	1 (0.17)	7
Navicula kotschyi		2 (0.33)	2
Navicula lenzii	2 (0.3)		2
Navicula libonensis	3 (0.44)		3
Navicula recens	2 (0.3)		2
Navicula reichardtiana		13 (2.17)	13
Navicula rostellata		2 (0.33)	2
Navicula secreta v. *apiculata*		3 (0.5)	3
Navicula spp.	2 (0.3)		2
Navicula symmetrica	4 (0.59)	2 (0.33)	6
Navicula tripunctata	1 (0.15)	9 (1.5)	10
Navicula trivialis	1 (0.15)	1 (0.17)	2
Navicula veneta	0.5 (0.07)	1 (0.17)	1.5
Neidium apiculatum	1 (0.15)		1
Nitzschia amphibia		1 (0.17)	1
Nitzschia angustata		6 (1)	6
Nitzschia dissipata	44 (6.49)	18 (3)	62
Nitzschia filiformis	2 (0.3)	1 (0.17)	3
Nitzschia fonticola		4 (0.67)	4
Nitzschia frustulum	20 (2.95)		20
Nitzschia graciliformis	2 (0.3)		2
Nitzschia gracilis		8 (1.33)	8
Nitzschia heufleriana	0.5 (0.07)		0.5
Nitzschia inconspicua		11 (1.83)	11
Nitzschia intermedia	0.5 (0.07)	2 (0.33)	2.5
Nitzschia palea	32 (4.72)		32
Nitzschia palea v. *debilis*		8 (1.33)	8
Nitzschia recta		12 (2)	12
Nitzschia sigma	0.5 (0.07)		0.5
Nitzschia sigmoidea	2 (0.3)		2
Nitzschia siliqua		3 (0.5)	3

Table C2. *Diatom species list and abundance from long-term stations from GRKO SEI sample events in 2008 and 2009 (continued).*

Taxa	Sample Date		Total Count
	10/4/2007	8/11/2009	
Nitzschia sociabilis		2 (0.33)	2
Nitzschia solita	8 (1.18)	2 (0.33)	10
Nitzschia subtilis		11 (1.83)	11
Nitzschia supralitorea	2 (0.3)		2
Nitzschia vermicularis	8 (1.18)		8
Placoneis clementioides	0.5 (0.07)		0.5
Placoneis clementis		2 (0.33)	2
Placoneis pseudanglica	2 (0.3)		2
Planothidium frequentissimum	2 (0.3)		2
Pleurosigma delicatulum	0.5 (0.07)		0.5
Pseudostaurosira brevistriata	10 (1.48)		10
Reimeria sinuata	2 (0.3)	1 (0.17)	3
Reimeria uniseriata		6 (1)	6
Rhoicosphenia abbreviata	4 (0.59)	7 (1.17)	11
Rhopalodia gibba	7 (1.03)	17 (2.83)	24
Sellaphora pupula	5 (0.74)	3 (0.5)	8
Staurosira venter	2 (0.3)		2
Stephanodiscus medius		2 (0.33)	2
Surirella brebissonii		2 (0.33)	2
Surirella minuta		2 (0.33)	2
Synedra acus		4 (0.67)	4
Synedra ulna	17 (2.51)		17
Tryblionella apiculata	6 (0.89)		6
	677.5 (1.47)	600 (1.61)	1277.5

Appendix D: Quality Assurance and Quality Control Overview

The ROMN SEI protocol and associated SOPs (Schweiger et al. In Review) including the ROMN Quality Assurance Performance Plan (QAPP) specify various quality assurance and quality control (QAQC) procedures and should be consulted for a complete treatment of this important topic. Table D1 lists the various steps associated with the protocol to ensure data quality and assurance throughout the data lifecycle. All collection and measurement procedures were standardized among all field crews. Field protocols and other activities were documented in peer reviewed SOPs. All field crew personnel participated in a standardized field training session. Field trainers were experienced NPS ROMN staff. Each training session was 1-2 days, and included lectures, field demonstrations, and at least one practice field exercise. The field operations manual served as the basis for the field training program. Field crews often had experienced ROMN staff or collaborators as core members. Field crews were offered an opportunity at the end of each year to suggest improvements to the field operations manual and other aspects of field operations. Systematic errors were minimized by using

Table D1. ROMN SEI quality control and quality assurance measures.

Core QA and QC Measure	Description of the Action
Documentation	Documentation via protocol, SOPs, methodology, etc. readily accessible
Training	Pre-season training of field crew
Field datasheets	Datasheets with standardized codes, precision guidelines for measured values, and clearly documented methodology to complete the form
Field oversight	Crew leader/protocol lead oversight during the field season and or periodically during data collection
Field datasheet review	End of the day or end of week quality assurance review of field datasheets for completeness, recording errors, and legible handwriting.
Data entry quality control	Data entry quality control measures, including electronic data collection devices, to eliminate misspellings, to standardize entry, and reduce errors (drop down menus, value range, limited lists, check boxes, and species lists)
Quality assurance post-data entry	Quality assurance review following SOP DM Quality Assurance and Quality Control Queries are applied to the data post-data entry to isolate errors. All tests and procedures should be documented in SOP SEI: Quality Control and Quality Assurance.
Quality assurance post-analyses	Quality assurance tests for derived data prior to uploading to the database. All tests and procedures should be documented in SOP SEI: Quality Control and Quality Assurance.
Quality assurance queries for data recorded by a digital device	Data collected with electronic equipment must undergo tests using QA software, queries in MS Access, or graphical review in MS Excel for outliers and missing data. Criteria must be developed for accepting or omitting data. All tests and procedures should be documented in SOP SEI: Quality Control and Quality Assurance
Lab data quality control	Protocol methodology establishes quality control pertaining to the sample collection. ROMN assumes contract labs maintain a level of quality control that is tractable internally.
Lab data quality assurance	Chain of custody forms are crosswalked with lab sample results for completeness. Data results are reviewed by the Protocol lead for outliers and missing data prior to uploading to the database.
Species lists	At the end of the field season, the species list, with additions from the current year, are crosswalked and updated with code and names as listed in NPSpecies, ITIS, CNHP, Weber, and USDA Plants. Database is updated prior to data entry.

validated methodologies and standardized procedures.

The ROMN QAPP presents details on Measurement Quality Objectives intended to demonstrate how ROMN monitoring generates data of known and documented quality, resulting in complete, accurate and transferable information. Data credibility necessary for the intended uses will be achieved when it is:

- consistent over time and consistent between staff members
- collected and analyzed using standardized and acceptable techniques
- comparable to data collected in other assessments using the same methods
- used appropriately to make decisions based on sound statistics

The ROMN QAPP also provides a summary of Data Quality Objectives or quantitative and qualitative terms that describe how good data need to be in order to meet project objectives. Data Quality Objectives for measurement data (or data quality indicators) are discussed in detail below but are listed by NPS WRD as:

- Target population
- Sensitivity
- Representativeness
- Completeness
- Data comparability
- Measurement sensitivity and detection limits
- Measurement precision as repeatability (accuracy)
- Measurement systematic error/bias

All of the various data components of the SEI protocol were managed at the ROMN offices. Completed field forms were reviewed and entered into a database with several internal QAQC checks. At least 10% of the forms were randomly selected and all data was confirmed. Any systematic errors were evaluated to assess if there was a persistent error with a need for a global correction. Data were reviewed and validated to be sufficiently representative, accurate, precise, and complete.

Laboratory Quality Assurance and Quality Control

Quality Assurance and Control (QAQC) performed by ROMN contract labs involves specific tasks undertaken to determine the reliability of field and laboratory results. It is accomplished internally by routinely analyzing blanks, duplicates, and spikes in the day-to-day operation of a laboratory, or externally by incorporating field-originated blanks, duplicates, and spikes into the set of the samples collected within the SEI protocol. The general objectives of lab QAQC are to ensure that: (1) the integrity of data generated in a monitoring effort is not compromised by extraneous sources of contamination (blanks), (2) the reported data are favorably comparable to the true values (accuracy), and (3) the results of a sample collection and measurement process (data generated by analytical procedures) are reproducible (precision).

Rigorous QAQC procedures were also applied to periphyton and macroinvertebrate samples. Diatom and macroinvertebrate data accuracy and precision were assured by a blind, quantitative quality-assurance approach, with a minimum of 10% of samples randomly selected for analysis. Bray-Curtis similarity between counts and identification performed independently by two analysts on QAQC samples was required to exceed 95% (Bray and Curtis 1957). If the required accuracy was not met, the samples were reanalyzed with lessons learned from this applied to all samples.

Table D2 presents laboratory detection limits for LIBI chemistry data collected between 2007 and 2009.

Table D2. Water chemistry detection limits for LIBI 2007-2010 data.

Constituent	Units	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.	Standard Error
Alkalinity Carbonate as $CaCO_3$ Total	mg $CaCO_3$/L	1	0.8	0.8	0.8	0.8		
Aluminum Dissolved	µg/L	8	532.5	100.0	100.0	3560.0	1223.29	432.50
Aluminum Total	µg/L	7	100.0	100.0	100.0	100.0	0.00	0.00
Arsenic Dissolved	µg/L	7	7.4	10.0	4.0	10.0	3.21	1.21
Arsenic Total	µg/L	7	7.4	10.0	4.0	10.0	3.21	1.21
Barium Dissolved	µg/L	3	4.0	4.0	4.0	4.0	0.00	0.00
Barium Total	µg/L	3	4.0	4.0	4.0	4.0	0.00	0.00
Beryllium Dissolved	µg/L	3	1.0	1.0	1.0	1.0	0.00	0.00
Beryllium Total	µg/L	3	1.0	1.0	1.0	1.0	0.00	0.00
Cadmium Dissolved	µg/L	3	0.2	0.2	0.2	0.2	0.00	0.00
Cadmium Total	µg/L	3	0.2	0.2	0.2	0.2	0.00	0.00
Calcium Dissolved	mg/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Calcium Total	mg/l	0						
Carbon organic Dissolved	mg C/L	8	0.1	0.1	0.1	0.2	0.06	0.02
Carbon organic Suspended	mg/L	0						
Carbon organic Total	mg C/L	4	0.5	0.5	0.5	0.5	0.01	0.00
Chloride Dissolved	mg/L	8	0.0	0.0	0.0	0.3	0.08	0.03
Chromium Dissolved	µg/L	3	2.0	2.0	2.0	2.0	0.00	0.00
Chromium Total	µg/L	3	2.0	2.0	2.0	2.0	0.00	0.00
Color True Total	sµ	0						
Conductivity Total	µmhos/cm	1	0.5	0.5	0.5	0.5		
Copper Dissolved	µg/L	7	7.1	5.0	5.0	10.0	2.67	1.01
Copper Total	µg/L	7	7.1	5.0	5.0	10.0	2.67	1.01
Fluoride Dissolved	mg/L	3	0.2	0.2	0.2	0.2	0.00	0.00
Hardness carbonate Dissolved	mg $CaCO_3$/L	7	0.6	0.1	0.1	1.3	0.64	0.24
Iron Dissolved	µg/L	7	100.0	100.0	100.0	100.0	0.00	0.00
Iron Total	µg/L	7	100.0	100.0	100.0	100.0	0.00	0.00
Lead Dissolved	µg/L	7	3.9	6.0	1.0	6.0	2.67	1.01
Lead Total	µg/L	7	3.9	6.0	1.0	6.0	2.67	1.01
Magnesium Dissolved	mg/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Manganese Dissolved	µg/L	7	1.2	1.2	1.2	1.2	0.00	0.00
Manganese Total	µg/L	7	6.6	10.0	2.0	10.0	4.28	1.62
Nickel Dissolved	µg/L	3	2.0	2.0	2.0	2.0	0.00	0.00
Nickel Total	µg/L	3	2.0	2.0	2.0	2.0	0.00	0.00
Nitrogen Ammonium NH_4 as N Dissolved	mg N/L	8	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen Dissolved	mg N/L	8	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen inorganic Dissolved	mg N/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen Nitrate NO_3 as N Dissolved	mg N/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen Nitrite NO_2 as N Dissolved	mg N/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen Nitrite NO_2 Nitrate NO_3 as N Dissolved	mg N/L							
Nitrogen organic Dissolved	mg N/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen Suspended	mg N/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Nitrogen Total	mg N/L	8	0.0	0.0	0.0	0.0	0.00	0.00
pH Total	sµ	0						
Phosphorus Dissolved	mg P/L	8	0.0	0.0	0.0	0.0	0.00	0.00
Phosphorus organic as P Dissolved	mg P/L	7	0.0	0.0	0.0	0.0	0.00	0.00

Table D2. *Water chemistry detection limits for LIBI 2007-2010 data (continued).*

Constituent	Units	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.	Standard Error
Phosphorus orthophosphate as P Dissolved	mg/L	8	0.0	0.0	0.0	0.0	0.00	0.00
Phosphorus phosphate PO_4 as P Dissolved	mg P/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Phosphorus Suspended	mg P/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Phosphorus Total	mg P/L	8	0.0	0.0	0.0	0.0	0.00	0.00
Potassium Dissolved	mg/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Potassium Total	mg/L	0						
Selenium Dissolved	µg/L	7	6.1	10.0	1.0	10.0	4.81	1.82
Selenium Total	µg/L	7	6.1	10.0	1.0	10.0	4.81	1.82
Silicon as Si Dissolved	mg Si/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Silicon as SiO_2 Dissolved	mg Si/l	8	0.0	0.0	0.0	0.2	0.08	0.03
Silicon as SiO_2 Total	mg SiO_2/L	3	0.2	0.2	0.2	0.2	0.00	0.00
Silver Dissolved	µg/L	3	0.5	0.5	0.5	0.5	0.00	0.00
Silver Total	µg/L	3	0.5	0.5	0.5	0.5	0.00	0.00
Sodium Dissolved	mg/L	7	0.0	0.0	0.0	0.0	0.00	0.00
Sodium Total	mg/L	0						
Solids Total Suspended TSS Suspended	mg/l	4	3.1	4.0	0.5	4.0	1.78	0.89
Sulfur sulfate SO_4 as SO_4 Dissolved	mg SO_4/L	8	0.0	0.0	0.0	0.1	0.04	0.01
Turbidity Total	NTU	1	0.3	0.3	0.3	0.3		
Zinc Dissolved	µg/L	3	40.0	40.0	40.0	40.0	0.00	0.00
Zinc Total	µg/L	3	40.0	40.0	40.0	40.0	0.00	0.00

Appendix E: Glossary

AFDW: Ash free dry weight. The weight (mass) of a material obtained by first drying the material at 105ºC and then heating the material to 500ºC for 1 hour.

Algae: Aquatic organisms that photosynthesize but lack a vascular system; some are microscopic, others very large.

Aquatic Macroinvertebrate or Benthic Macroinvertebrate: An organism found in waterbodies, frequently associated with stream bottoms, not having a spinal column and which is visible with the naked eye.

Assessment Point/Reference Value: A state or range of states used to assess or evaluate monitoring data. When this is numeric we refer to it as a reference value. They may be narrative only, but these are less useful in long-term monitoring. They may be an ecological threshold, a management-based threshold, a period of record baseline, or if there is nothing else available, an arbitrary value (which is used through time for comparative purposes only).

Baseflow: The portion of streamflow that comes from groundwater and not runoff.

Baseline: A value or range of values calculated from a time series of data (from one to many years; if many, the time period is often referred to as a "Period of Record"). Baselines may not necessarily be an ecological or management threshold, but could be used in a similar way to assess monitoring data.

Beneficial Use: A valuable characteristic of a stream or river resource that, directly or indirectly, contributes to human welfare.

Benthic: On or associated with the sediments or bottom of a body of water.

Biomass: The total mass or amount of living or dead organisms in a particular area or volume.

Biochemical Oxygen Demand (BOD): A measure of, as well as a procedure for determining, how fast oxygen is used up in water. BOD is usually measured as the rate of oxygen uptake by microorganisms in a water sample, at 20°C, in the dark, over a five-day period.

Chlorophyll-a: The major green pigment found in the chloroplasts of plants and algae.

Criteria: A threshold set by well-established regulatory process; may or may not be ecologically or management relevant for a park resource.

Density: Quantity of a number per unit area, volume, or mass.

Diatom: Any one of a number of microscopic algae, which can live as single cells or in colonies, that are enclosed within two box-like parts or valves (called frustules) made of silica that fit together like the halves of a Petri dish.

Desired Future Condition (DFC): Describes a desired reference condition from a management perspective. Usually expressed in a narrative form that makes application to monitoring data less direct. The NPS defines the DFC a "park's natural and cultural resource conditions that the NPS aspires to achieve and maintain over time, and the conditions necessary for visitors to understand, enjoy, and appreciate those resources."

Diel: Involving a 24-hour period that usually includes a day and the adjoining night.

Ecological Threshold: In general, this is a break point(s) or a "break range" that describes a shift in an ecological response measure and bounds regions in a response's distribution. Thresholds often describe meaningful changes in the ecology of a system. They may involve a non-linear, rapid, or large response relative to the inputs to a system. They often create a new state from which is difficult to recover.

Ephemeral Stream: A stream or stream segment that flows only in direct response to precipitation in the immediate watershed or in response to the melting of a cover of snow and ice and whose channel bottom is always above the local water table.

Eutrophication: The process of enrichment of a waterbody by nutrients, usually nitrogen- and phosphorus-containing compounds, and the resulting increase in primary productivity (algal and plant growth and decay). Some definitions include organic enrichment of a waterbody as part of eutrophication.

Fixation (Nitrogen Fixation): The process by which nitrogen is taken from its relatively inert gas form in the atmosphere (N_2) and converted into nitrogen compounds such as nitrate and ammonia.

Geospatial: Pertaining to the geographic location and characteristics of natural or constructed features and boundaries on, above, or below the earth'' surface; especially referring to data that are geographic and spatial in nature.

Intermittent Stream: A stream or stream segment that is below the local water table for at least some part of the year and obtains its flow from both surface run-off and groundwater discharge.

Least Disturbed Condition (LDC): In some (if not many) cases, the lack of availability of a minimally disturbed condition (MDC) or a completely undisturbed reference site makes it necessary to resort to the concept of "least-disturbed condition." Least-disturbed condition is defined as the best available state within a defined region. The LDC may include measurable anthropogenic stress and disturbance. The concept of a LDC implies that there may be an opportunity for management or restoration of sites to a MDC or best attainable state. This may also be possible with a MDC, but in many cases the set of actions (i.e., reverse climate change) are beyond the scope of management.

Macrophyte: Macroscopic aquatic vascular plants capable of achieving their generative cycles with all or most of the vegetative parts submerged or supported by the water.

Mainstem: The principal river within a given drainage basin, in the case where a number of tributaries discharge into a larger watercourse.

Management-based Threshold: An assessment point with explicit management applications or where management-relevant changes in a response occurs. Management thresholds may be the same as ecological thresholds, especially in wilderness parks or when there is no or little information about the management relevance of a response (in these cases we generally refer to an ecological threshold). They may be set at some estimated distance from an ecological threshold to serve as a warning ("surveillance threshold") or to spur management action ("action threshold").

Metric: A characteristic of a biological assemblage (e.g., fishes, algae) that changes in some predictable way with increased human influence.

Minimally Disturbed Condition (MDC): A reference condition characterized by the absence of significant human disturbance. In practice, even in wilderness parks, there is usually some background human impact due to diffuse or indirect factors like climate change, nutrient deposition, or residual historic alterations.

Narrative Water Quality Criteria: Statements codified in state law that describe, in a concise way, a water quality condition that must be maintained in order to protect beneficial uses.

Nonpoint Source: The source of pollutants which originates from diffuse runoff, seepage, drainage, or infiltration.

Numeric Water Quality Criteria: Quantified expressions of water quality in state law intended to protect a designated beneficial use or uses.

Organic Enrichment: From a water pollution perspective, the addition of decomposable plant or animal material, or their wastes, to a waterbody.

Perennial Stream: A stream or stream segment that has flowing water year-round except during extreme drought.

Periphyton: The microscopic flora and fauna that grow or are associated with the bottom of a body of water and includes microscopic algae, bacteria, and fungi.

Phytoplankton: Free living, generally microscopic algae commonly found floating or drifting in waterbodies such as the ocean, lakes, and streams.

Point Source: A discernable, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, or vessel or other floating craft, from which pollutants are or may be discharged.

Primary Productivity: The production of organic compounds from carbon dioxide, principally through the process of photosynthesis.

Reference Condition(s): The region of a response distribution on the "good side" of a (usually ecological) threshold. The reference condition is a distribution as it encompasses natural variation in the response. It is somewhat synonymous with a Natural Range of Variability. Some authors restrict reference condition to describe a biological response, but the ROMN proposes using it more loosely to refer to any type of response measure. Reference conditions are defined relative to a specific response, target population and spatiotemporal scale (i.e., this is different for a wetland response in Rocky Mountain National Park than for the Southern Rockies ecoregion). Based on the dominant landscape condition, reference conditions may reflect various degrees of background disturbance.

Salmonids: Ray-finned fish, whose members include salmon, trout, chars, freshwater whitefishes, and graylings.

Saturation: A state in which the gas concentration (e.g., oxygen) in a waterbody is in equilibrium with the local partial pressure of that gas in the atmosphere.

Standards (Water Quality Standards): In a water quality regulatory context, a term applicable to state waters referring collectively to their designated beneficial uses, criteria, and the non-degradation policy, all in Montana law.

Strahler Order: A simple hydrology algorithm used to define stream size based on a hierarchy of tributaries. Streams at the top of the watershed are labeled 1. When two order-1 streams join, they create an order-2 stream. When two order-2 streams join, they create an order-3 stream, and so on. If a stream of lower order (e.g., order-2) joins a stream of higher order (e.g., order-3), the order number of the latter does not change.

Wadeable: A stream whose Strahler order is first through (at most) sixth (1:100,000 map scale) in which most of the wetted channel is wadeable by a person during baseflow conditions.

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